THE PHYSICAL SOCIETY OF LONDON.

PROCEEDINGS.

VOLUME XXXIV.—PART V.

AUGUST 15, 1922.

Price to Non-Fellows, **6s.** *net, post free* **6/3.**

Annual Subscription, **30/-** *post free, payable in advance*

Published Bi-Monthly from December to August.

LONDON:
FLEETWAY PRESS, LTD.,
3-9, DANE STREET, HIGH HOLBORN, W.C.1.

1922.

THE PHYSICAL SOCIETY OF LONDON.

1922-23.

OFFICERS AND COUNCIL.

President.

ALEXANDER RUSSELL, M.A., D.Sc.

Vice-Presidents.

(WHO HAVE FILLED THE OFFICE OF PRESIDENT)

SIR OLIVER J. LODGE, D.Sc., F.R.S.
SIR RICHARD GLAZEBROOK, K.C.B., D.Sc., F.R.S.
C. CHREE, Sc.D., LL.D., F.R.S.
PROF. H. L. CALLENDAR, M.A., LL.D., F.R.S.
SIR ARTHUR SCHUSTER, PH.D., Sc.D., F.R.S.
SIR J. J. THOMSON, O.M., D.Sc., F.R.S.
PROF. C. VERNON BOYS, F.R.S.
PROF. C. H. LEES, D.Sc., F.R.S.
PROF. SIR W. H. BRAGG, K.B.E., M.A., F.R.S.

Vice-Presidents.

THE RT. HON. LORD RAYLEIGH, F.R.S.
PROF. T. MATHER, F.R.S.
T. SMITH, B.A.
PROF. G. W. O. HOWE, D.Sc.

Secretaries.

F. E. SMITH, O.B.E., F.R.S.
"Redcot," St. James's Avenue, Hampton Hill, Middlesex

D. OWEN, B.A., D.Sc.
62, Wellington Road, Enfield, Middlesex.

Foreign Secretary.

SIR ARTHUR SCHUSTER, PH.D., Sc.D., F.R.S.

Treasurer.

W. R. COOPER, M.A., B.Sc.
82, Victoria Street, S.W.1.

Librarian.

PROF. A. O. RANKINE, D.Sc.
Imperial College of Science and Technology.

Other Members of Council.

J. H. BRINKWORTH, B.Sc.
G. B. BRYAN, D.Sc.
C. R. DARLING, F.I.C.
PROF. C. L. FORTESCUE, O.B.E.
E. GRIFFITHS, D.Sc.
J. GUILD, A.R.C.Sc., D.I.C.
F. L. HOPWOOD, D.Sc.
E. A. OWEN, B.A., D.Sc.
E. H. RAYNER, M.A., D.Sc.
J. H. VINCENT, D.Sc., M.A.

Assistant Secretary (Publications).

CAPT. C. W. HUME, M.C., B.Sc.
14, The Hawthorns, Finchley, N.3.

PROCEEDINGS

AT THE

MEETINGS OF THE PHYSICAL SOCIETY OF LONDON.

SESSION 1921—1922.

October 28, 1921.

Meeting held at the Imperial College of Science.

Prof. Sir W. H. BRAGG, K.B.E., M.A., F.R.S., President, in the Chair.

The following Papers were read :—

1. "On the Use of Anderson's Bridge for the Measurement of the Variations of the Capacity and Effective Resistance of a Condenser with Frequency," by S. BUTTERWORTH, M.Sc. (from the National Physical Laboratory).

2. "Notes on Earth Capacity Effects in Alternating Current Bridges," by S. BUTTERWORTH, M.Sc. (from the National Physical Laboratory).

3. "An Automatic Voltage Regulator," by Mr. F. G.H. LEWIS (with demonstration).

4. "The Flow of Viscous Liquids Through Slightly Conical Tubes," by Prof. A. S. HEMMY.

November 11, 1921.

Meeting held at the Imperial College of Science.

The Presidental Address was delivered by Prof. Sir W. H. BRAGG, K.B.E., M.A., F.R.S., who took as his subject "The Structure of Organic Crystals."

November 25, 1921.

Meeting held at the Imperial College of Science.

Prof. Sir W. H. BRAGG in the Chair.

A Discussion on Hygrometry was held, the following Papers being first read :—

1. "Some Modified Forms of Hygrometers," by Dr. EZER GRIFFITHS (National Physical Laboratory).

2. "The Theory of the Hair Hygrometer," by F. J. W. WHIPPLE, M.A. (Meteorological Office).

3. "The Rationale of Glaisher's System of Hygrometry," by F. J. W. WHIPPLE, M.A.

4. "The Wet and Dry Bulb Hygrometer," by Principal SKINNER, M.A.

5. "Determination of the Proper Constant in Apjohn's Formula for Use in Aeroplanes," by WATSON WATTS.

6. "A New Form of Absorption Hygrometer," by H. G. MAYO, M.A., and Prof. A. M. TYNDALL.

7. "A Thermal Hygrometer," by Prof. A. M. TYNDALL and Prof. A. P. CHATTOCK.

The meeting was preceded by Demonstrations and an Exhibition of Apparatus.

December 9, 1921.

Meeting held at the Imperial College of Science.

Prof. Sir W. H. BRAGG, and subsequently Dr. ALEXANDER RUSSELL, in the Chair.

The following Papers were read :—

1. "The Average Range of β-Particles in Different Metals," by G. A. SUTHERLAND, M.A., and L. H. CLARK, B.Sc.

2. "The Sensitivity of Ballistic Galvanometers," by Prof. ERNEST WILSON.

3. "The Estimation of the Radium Content of Radio-active Luminous Compounds," by E. A. OWEN, D.Sc., and WINIFRED E. FAGE, B.Sc. (National Physical Laboratory).

The following Paper was taken as read in the absence of the Author :—

4. "The Determination of the Damping Decrement of a Tuning Fork," by Prof. F. Ll. Jones.

Dr. F. Ll. HOPWOOD Exhibited a number of Optical Experiments :—

1. A New Effect with a Modified Strouhal Apparatus.

2. The Auto Stroboscope.

3. An Incandescent Colour Top.

January 4 and 5, 1922.

The Twelfth Annual Exhibition of Electrical, Optical and other Physical Apparatus was held by the Physical Society and the Optical Society at the Imperial College of Science.

The following Discourses were delivered :—

On January 4th and 5th :—"The Johnsen-Rahbek Electrostatic Telephone and its Predecessors," by ALAN A. CAMPBELL SWINTON, F.R.S.

On Janary 4th :—" Radium : its application in Peace and War," by Mr. F. HARRISON GLEW. Professor F. J. CHESHIRE, C.B.E., in the chair.

On January 5th :—" The Employment of Coarse Wire Gratings in Astronomy," by Sir FRANK WATSON DYSON, F.R.S., F.R.A.S., Astronomer Royal.

January 27, 1922.

Meeting held at the Imperial College of Science.

Prof. Sir W. H. BRAGG in the Chair.

The following Papers were read :—

1. " On the Diffusion of Solutions," by T. H. LITTLEWOOD, M.A., B.Sc. (University College, Reading).

2. " On a Special Apparatus for the Measurement at Various Temperatures of the Thomson Effect in Wires," by H. R. NETTLETON, M.Sc. (Birkbeck College, London).

3. " A Defect in the Sprengel Pump : its Causes and a Remedy," by J. J. MANLEY, M.A. (Magdalen College, Oxford).

February 10, 1922.

Annual General Meeting.

Held at the Imperial College of Science.

Prof. Sir W. H. BRAGG in the Chair.

GENERAL BUSINESS.

The Annual Report was read by the Secretary, Mr. F. E. SMITH, O.B.E., F.R.S., and the Report of the Treasurer was read by the Treasurer, Mr. W. R. COOPER, M.A., B.Sc. Both Reports were unanimously adopted.

ANNUAL REPORT.

During the year 1921, 14 ordinary Science Meetings and one Special General Meeting of the Society were held. Of these the Special General Meeting and 13 ordinary meetings were held at the Imperial College of Science ; the remaining ordinary meeting was held, by invitation of the President, at University College.

Two of the ordinary meetings were devoted to discussions. The first of these was on " Absolute Measurements of Electrical Resistance and Instruments based on the

Temperature-Variation of Resistance," and the second was on "Hygrometry." Exhibits and demonstrations were arranged in connection with both discussions.

The Guthrie Lecture was delivered by Professor A. A. Michelson of the University of Chicago, who chose as his subject "Some Recent Applications of Interference Methods." The meeting was one of the most successful ever held by the Society.

On June 10th Sir Ernest Rutherford, F.R.S., delivered a special lecture on "The Stability of Atoms," and on November 11th Sir W. H. Bragg, F.R.S., gave his Presidential address, choosing as his subject "The Structure of Organic Crystals."

These discussions and lectures, five in all, were most successful; each was attended by over 130 Fellows and visitors and the average attendance was 155.

Excluding the Discussions, the Guthrie Lecture and the two special addresses, the average attendance at the ordinary meetings was 58.

In co-operation with the Optical Society the Eleventh Exhibition of Scientific Apparatus was held on January 5th and 6th. Fifty firms exhibited apparatus and many of them arranged very interesting demonstrations. About 2,500 Fellows and visitors attended the Exhibition. Dr. Morrison, on behalf of Emeritus Professor Archibald Barr, gave two lectures on "The Optophone, an instrument which enables the totally blind to read ordinary print," Professor Sir W. H. Bragg, F.R.S., delivered a lecture on "Sounds in Nature," and Professor C. R. Darling gave a discourse on "Some Unusual Surface Tension Phenomena." The lectures were experimentally illustrated and were attended by large audiences.

Early in the year the Council considered the size of page, the type and the quality of paper for the "Proceedings," and as a result of a Report by a special committee all of these were changed. The size of the new "Proceedings" is very similar to that of the "Proceedings of the Royal Society" and identical with the "Proceedings" of the Optical Society.

It is regretted that the arrangement has terminated by which Fellows obtained at a reduced rate the "Proceedings of the Royal Society." The Council is of opinion that the publications of any scientific society should be sold at a slightly reduced rate to Fellows of other Scientific Societies, and has asked the Conjoint Board to consider the practicability of such an arrangement.

Professor A. Fowler, F.R.S., has prepared for the Society a Report on "Series in Line Spectra." This will shortly be issued gratis to Fellows. A second Report on "Atomic Structure," by Professor Bohr, is in preparation.

An appeal for funds for a Duddell Memorial medal resulted in a sum of about £650 being raised. The Committee dealing with the memorial have asked Mrs. Mary G. Gillick to undertake the preparation of the medal, and it is hoped that the medal will be ready during the early part of 1922. The Society is greatly indebted to Mr. R. S. Whipple, who acted as Honorary Secretary to the Memorial Committee.

Mr. J. Guild, who acted as Assistant Secretary to the Society, for the purposes of its publications, resigned in June, and Capt. C. W. Hume was appointed Assistant Secretary in July. Mr. Guild had served the Society for nine years, and his resignation was received with much regret.

The number of Honorary Fellows on the Roll on December 31st, 1921, was nine, and the number of ordinary Fellows and Students was 534.

Forty-eight new Fellows and four Students were elected during the year and there were seven resignations.

The Society has to record with regret the deaths of Professor Lippmann, Mr. H. Durham, Mr. A. Howard, Mr. H. T. Gerrans, and Mr. H. E. Axford.

Professor Lippmann was an Honorary Fellow of the Society since 1907, Mr. Durham and Mr. Gerrans were Life Members of the Society, Mr. Howard was a Member for nearly 40 years, and Mr. H. E. Axford was a Student Member.

Report of the Treasurer.

Notwithstanding increased activities on the part of the Society, the year's revenue has been sufficient to meet the year's expenditure and to leave a small margin. The income has increased, being £1,660 5s. 4d., as compared with £1,513 2s. 8d. for the previous year. The increase has been due mostly to payments by exhibitors to meet the cost of printing the catalogue of the Exhibition, the Council having decided that this cost was becoming too high to impose on the Society as hitherto without any charge being made. The only other considerable increase in income is due to the steady rise in membership, which is a most satisfactory feature. The loss in revenue due to reductions in subscriptions under the arrangement made with the Institute of Physics amounted to £14 6s. 9d. The sum realised by sales of publications has fallen slightly, notwithstanding the increased prices that have been in force. This is probably due partly to the fact that the sales have depended less upon special reports than in the year before.

The expenditure on printing has been very heavy, not only on the " Proceedings " and usual publications (an increase of £88 5s. 9d.), but on special publications (£163 14s. 7d.). The latter include a reprint of Prof. Eddington's Report on Relativity, the discussion on Reflecting Surfaces, held with the Optical Society, and the discussion on Colloids, held with the Faraday Society. The total is thus £1,095 15s. 7d., as compared with £843 15s. 3d. in the previous year.

With regard to the Balance Sheet, it may be said that the subscriptions in arrears are becoming less serious. The investments have been valued at market prices through the courtesy of the Manager of the London County Westminster & Parr's Bank, and for the first time for many years they show a small appreciation. The deposit at the bank has increased by £150, and the total cash (including deposit), after adjustment, amounts to £427 5s. 7d., as compared with £408 17s. 1d. in the previous accounts.

Having regard to the high costs still prevailing the position may be said to be very satisfactory.

Votes of Thanks.

The following Votes of Thanks were passed :—

To the Hon. Auditors (Mr. R. S. Whipple and Dr. E. A. Owen), proposed by Dr. H. Borns and seconded by Mr. B. W. Clack.

To the Retiring Officers and Council, proposed by Col. O'Meara and seconded by Mr. R. W. Paul.

To the Governing Body of the Imperial College of Science, proposed by Prof. Eccles and seconded by Dr. Rankine.

INCOME AND EXPENDITURE ACCOUNT.

From January 1st to December 31st, 1921.

Income.	£	s.	d.	£	s.	d.
Entrance Fees		49	7 0			
Subscriptions by Fellows direct		596	8 11			
„ through Institute of Physics		79	19 3			
„ Voluntary*		15	15 0			
„ by Students		5	5 0			
„ Arrears paid		36	17 6			
„ Paid in Advance		39	7 6			
„ for "Science Abstracts" and Advance Proofs		30	7 6			
				853	7	8
Composition Fees				73	10	0
Dividends:—						
Furness Debenture Stock		11	3 10			
Midland Railway		28	0 0			
Metropolitan Board of Works		7	0 0			
Lancaster Corporation Stock		8	8 0			
New South Wales Stock		8	17 10			
London, Brighton & South Coast Railway		17	10 0			
Great Eastern Railway		14	0 0			
India 3½% Stock		17	10 0			
Funding Loan		18	4 0			
				130	13	8
Income Tax refunded				44	18	4
Interest on deposit account				21	3	6
Sales of Publications (Fleetway Press, Ltd.)				426	18	11
Optical Society (for Exhibition)				11	0	0
Exhibitors' payments on account of catalogue				98	13	3
				£1,660	5	4

Expenditure.	£	s.	d.	£	s.	d.
"Science Abstracts"				297	18	6
Fleetway Press, Ltd.:—						
"Proceedings"	605	17	5			
Bulletin	65	4	3			
Distribution (Postage)	82	14	7			
General, including printing for Exhibition	178	4	9			
				932	1	0
Sundry Publications:—						
Report on Relativity (reprint)	56	17	6			
Discussion on Reflecting Surfaces (report)	40	1	1			
Discussion on Colloids (report)—reserve	66	16	0			
				163	14	7
Reporting	71	14	5			
Refreshments and Attendance	96	3	2			
Petty Cash—						
Secretaries' Expenses	23	16	9			
Treasurer's Expenses	21	8	6			
Guthrie Lecture (Honorarium)	10	0	0			
Periodicals	3	17	8			
Insurance	2	3	0			
F. S. Spiers (registered address)	2	2	0			
Bank Charges		3	0			
Cheque Book		10	0			
				231	18	6
Conjoint Board of Scientific Societies				10	0	0
Total Expenditure for the Year				1,635	12	7
Balance, being excess of income over expenditure				24	12	9
				£1,660	5	4

W. R. COOPER, *Honorary Treasurer.*

Audited and found correct,

ROBERT S. WHIPPLE
E. A. OWEN
} *Honorary Auditors.*

February 7th, 1922.

* Voluntary subscriptions are those paid by Fellows who have compounded at the low rate of £10.

BALANCE SHEET AT DECEMBER 31ST, 1921.

ASSETS.

	£	s.	d.	£	s.	d.
Subscriptions in arrears	59	6	6			
Less reserve for subscriptions probably unrealisable	25	0	0			
				34	6	6
Investments (valued at Dec. 31):—						
£533 Furness Railway 3 per cent. Debenture Stock	288	0	0			
£1,600 Midland Railway 2½ per cent. Perpetual Preference Stock	656	0	0			
£200 Metropolitan Board of Works 3½ per cent. Consolidated Stock	174	0	0			
£400 Lancaster Corporation 3 per cent. Redeemable Stock	208	0	0			
£254 2s. 9d. New South Wales 3½ per cent. Ordinary Stock	235	0	0			
£500 London, Brighton & South Coast Railway Ordinary Stock	240	0	0			
£500 Great Eastern Railway 4 per cent. Debenture Stock	350	0	0			
£500 India 3½ per cent. Stock	290	0	0			
£650 4% Funding Loan, 1960-90	494	0	0			
				2,935	0	0
Stock of Publications (Treasurer's valuation)				400	0	0
Cash at Bank, on Deposit	450	0	0			
Cash at Bank, Current Account	119	14	4			
	569	14	4			
Adjustment for outstanding cheques, &c.	142	11	4			
				427	3	0
Cash in hand (Treasurer's Petty Cash)				2	7	
				£3,796	12	1

LIABILITIES.

	£	s.	d.
Life Compositions	1,973	0	0
Balance, General Fund	1,823	12	1
	£3,796	12	1

W. R. COOPER, *Honorary Treasurer.*

February 7th, 1922.

Audited and found correct,

ROBERT S. WHIPPLE
E. A. OWEN
} *Honorary Auditors.*

LIFE COMPOSITION FUND AT DECEMBER 31ST, 1921.

		£	s.	d.
133	Fellows paid £10	1,330	0	0
3	Fellows paid £15	45	0	0
1	Fellow paid £20 10s.	20	10	0
11	Fellows paid £21	231	0	0
11	Fellows paid £31 10s.	346	10	0
159		£1,973	0	0

Audited and found correct,

W. R. COOPER, *Honorary Treasurer.*

February 7th, 1922.

ROBERT S. WHIPPLE
E. A. OWEN
Honorary Auditors.

ELECTION OF OFFICERS AND COUNCIL.

The election of Officers and Council for the year 1922-1923 was carried out, with the following results :—

President.—Alexander Russell, M.A., D.Sc.

Vice-Presidents (who have filled the office of President).—Sir Oliver J. Lodge, D.Sc., F.R.S., Sir Richard Glazebrook, K.C.B., D.Sc., F.R.S., C. Chree, Sc.D., LL.D., F.R.S., Prof. H. L. Callendar, M.A., LL.D., F.R.S., Sir Arthur Schuster, Ph.D., Sc.D., F.R.S., Sir J. J. Thomson, O.M., D.Sc., F.R.S., Prof. C. Vernon Boys, F.R.S., Prof. C. H. Lees, D.Sc., F.R.S., Prof. Sir W. H. Bragg, K.B.E., M.A., F.R.S.

Vice-Presidents.—The Rt. Hon. Lord Rayleigh, F.R.S., Prof. T. Mather, F.R.S., T. Smith, B.A., Prof. G. W. O. Howe, D.Sc.

Secretaries.—F. E. Smith, O.B.E., F.R.S., "Redcot," St. James's Avenue, Hampton Hill; D. Owen, B.A., D.Sc., 62, Wellington Road, Enfield.

Foreign Secretary.—Sir Arthur Schuster, Ph.D., Sc.D., F.R.S.

Treasurer.—W. R. Cooper, M.A., B.Sc., 82, Victoria Street, S.W.1.

Librarian.—A. O. Rankine, D.Sc., Imperial College of Science and Technology.

Other Members of Council.—J. H. Brinkworth, B.Sc., G. B. Bryan, D.Sc., C. R. Darling, F.I.C., Prof. C. L. Fortescue, O.B.E., E. Griffiths, D.Sc., J. Guild, A.R.C.Sc., D.I.C., F. L. Hopwood, D.Sc., E. A. Owen, B.A., D.Sc., E. H. Rayner, M.A., D.Sc., J. H. Vincent, D.Sc., M.A.

PAPERS.

The new President, Dr. ALEXANDER RUSSELL, M.A., D.Sc., being now in the Chair, the following Papers were read :—

1. "On the Measurement of the Radium Content of Sealed Metal Tubes," by E. A. OWEN, D.Sc., and BERTHA NAYLOR, B.Sc. (National Physical Laboratory).

2. "The Crystal Structure of Ice," by Sir WILLIAM BRAGG, F.R.S. (University College, London).

3. "A Method of Exciting Vibrations in Plates, Membranes, &c., Based on Bernouilli's Principle," by Dr. KERR GRANT (Adelaide University).

February 24, 1922.

Meeting held at the Imperial College of Science.

Dr. ALEXANDER RUSSELL in the Chair.

The following Papers were read :—

1. "The Number of Radio-active Transformations as Determined by Analysis of the Observations," by Dr. H. LEVY (Imperial College of Science).

2. "A Graphical Method of Treating Fresnel's Formulæ for Reflection in Transparent Media," by Prof. C. H. LEES, D.Sc., F.R.S. (East London College).

The following Demonstrations were given :—

3. Demonstrations of Apparatus by the Research Staff of the General Electric Co., London :—

(a) *Rapid Weighing Balance.*

(b) *Electrostatic Voltmeter.*

(c) *Apparatus for the Measurement of Density of Fine Wires.*

4. A Demonstration of the Physical Properties of Cellactite, by F. C. Dyche-Teague, B.Sc., F.I.C.

March 10, 1922.

Meeting held at the Imperial College of Science.

Dr. Alexander Russell in the Chair.

The following Papers were read, and illustrated by Exhibits and Demonstrations :—

1. "On the Electromagnetic Screening of a Triode Oscillator," by R. L. Smith-Rose, B.Sc., D.I.C. (The National Physical Laboratory).

2. "A New Form of High Vacuum Automatic Mercury Pump," by H. P. Waran, M.A., Ph.D. (University College, London).

3. "Viscosity Determination by Means of Orifices and Short Tubes," by W. N. Bond, M.Sc. (University College, Reading).

March 24, 1922.

Meeting held at the Imperial College of Science.

Dr. Alexander Russell in the Chair.

The Seventh Guthrie Lecture was delivered by Prof. N. Bohr, of the University of Copenhagen, the subject of his address being "The Effect of Electric and Magnetic Fields on Spectral Lines."

April 28, 1922.

Meeting held at the Imperial College of Science.

Dr. Alexander Russell in the Chair.

The following Papers were read :—

1. "The Position of Best Focus in the Presence of Spherical Aberration," by T. Smith, B.A., F.Inst.P. (National Physical Laboratory).

2. "The Determination of the Absolute Stress-variation of Refractive Index," by F. Twyman, A.I.E.E., and J. Perry.

3. "An Experimental Comparison of the Viscous Properties of (*a*) Carbon Dioxide and Nitrous Oxide, and (*b*) Nitrogen and Carbon Monoxide," by C. J. SMITH, B.Sc., A.R.C.Sc., D.I.C. (Imperial College of Science and Technology).

An optical sonometer was exhibited in action by Mr. F. TWYMAN, A.I.E.E., F.Inst.P. (A. Hilger, Ltd.).

May 12, 1922.

Meeting held at the Imperial College of Science.

Dr. ALEXANDER RUSSELL in the Chair.

1. A Demonstration of Some Electrical Properties of Neon-filled Lamps was given by S. O. PEARSON, B.Sc., and H. ST. G. ANSON.

2. A Paper was read, entitled "A New Apparatus for the Measurement of the Polarisation Capacity of Platinum Plates in Sulphuric Acid," by A. GRIFFITHS, D.Sc., and W. T. HEYS, B.Sc.

3. Some remarks on "The Molecular Forces involved in Cohesion" were presented by Dr. HERBERT CHATLEY.

May 26, 1922.

Meeting held at the Imperial College of Science.

Dr. ALEXANDER RUSSELL in the Chair.

A Lecture on "Atomic Weights and Isotopes" was delivered by Dr. F. W. ASTON, F.R.S. (Trinity College, Cambridge).

June 9, 1922.

Visit to the National Physical Laboratory, Teddington.

June 23, 1922.

Meeting held at the Imperial College of Science.

Dr. ALEXANDER RUSSELL in the Chair.

The following Papers were read :—

1. "An Experiment on Molecular Gyrostatic Action," by J. W. FISHER, B.Sc. (King's College, London) (communicated by Prof. O. W. Richardson, F.R.S.).

2. "On the Viscous Properties and Molecular Dimensions of Silicane," by Prof. A. O. RANKINE, D.Sc., and C. J. SMITH, B.Sc. (Imperial College of Science).

3. "The Pressure-Gradient in Liquids Flowing through Cones," by W. N. BOND, M.Sc. (University College, Reading).

The following Demonstrations were given :—

4. "A Mercury-Drop Method of Producing Visual Effects by Means of Sound," by Dr. E. E. FOURNIER D'ALBE.

5. (*a*) "A Magnetic Pivot," and (*b*) "A Self-charging Electroscope," by MAJOR C. E. S. PHILLIPS, O.B.E.

XXV. *An Experiment on Molecular Gyroscopic Action.*

By J. W. Fisher, B.Sc., *King's College, London.*

Received March 13, 1922.

(Communicated by Prof. O. W. Richardson.)

ABSTRACT.

Starting from the inference, pointed out by O. W. Richardson on the basis of electron theory, that the magnetization of a substance implies a moment of momentum about the axis of magnetization, the consequences of applying a rotating magnetic field to a specimen of magnetic material are analysed.

It is shown that magnetization in a direction transverse to the plane of the rotating field should result, in sense related to the direction of rotation of the field by the left-hand screw rule; and proportional in intensity to the first power of the angular velocity of the field and the susceptibility of the material.

Experimental tests were made, using a magnetometer, but without success, disturbing effects having not as yet been eliminated.

According to the electron theory the magnetization of a substance implies a moment of momentum about the axis of magnetization due to a resultant rotation of the electrons in one sense. This consequence was first pointed out, in connection with the electron theory, by O. W. Richardson* who found for the moment of momentum U per unit volume, taking account of both positive and negative electrons, the value

$$U_z = 2\frac{m}{e} I_z \left(\frac{1 - \frac{eMA}{Ema}}{1 - \frac{A}{a}} \right)$$

where M and m are the masses of the positive and negative electrons respectively, E and e their charges, A and a the average values of the projections of the areas of the orbits perpendicular to the axis of magnetization divided by the times in which they are described. I_z here denotes the intensity of magnetization. Let us assume that the magnetization arises entirely from the orbital motion of negative electrons, so that we can write

$$U_z = 2\frac{m}{e} I_z$$

Suppose now that a magnetizable substance is placed in a rotating magnetic field of strength H, which in the diagram we suppose revolving in the plane yx with uniform angular velocity Ω. If at any instant it coincides in direction with oy, then by the above relation there will be a moment of momentum about that axis equal to $2\frac{m}{e} I_y$. On account of the rotation of H, however, the rate of change of this moment of momentum about the perpendicular axis ox will be $2\frac{m}{e} I_y \Omega$, so that there should, by the conservation of angular momentum, be a mechanical couple of this amount acting on the material and tending to turn it about the axis ox. The material, however, being fixed, and the field revolving, the elementary magnets

* Richardson, Phys. Rev., Vol. XXVI., p. 248 (1908).

must, in part at any rate, revolve with the field, and the more so the stronger the magnetizing field (as is shown by the falling off of the hysteresis in strong rotating fields). We should expect, then, the magnetic axes of the elementary magnets to be deflected, under the directive force of the above-mentioned gyrostatic couple, in a direction perpendicular to the plane of rotation of the field, thus giving rise to a transverse intensity of magnetization. For the case of revolving negative electrons this transverse field will be directed in a left-handed screw sense with the direction of rotation of the external field.

To calculate the magnitude of this transverse intensity we introduce a co-ordinate system $x'\ y'\ z'$ revolving with the field, and we suppose the field H to be

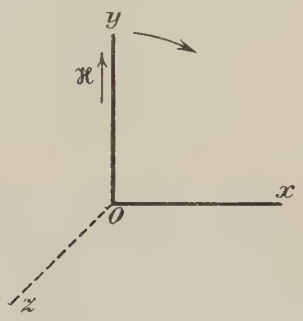

FIG. 1.

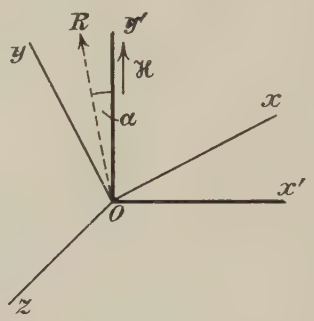

FIG. 2.

always directed along the oy' axis. M being the moment of momentum of an elementary magnet of magnetic moment m we have

$$M=2\frac{m}{e}\,\mathrm{m} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

We have, in a fixed co-ordinate system x, y, z, such that oz and oz' always coincide, $dM/dt=C$, where C is the moment of the external forces. Denoting differentiation with respect to the time by d'/dt, in the rotating system we can write

$$\frac{dM}{dt}=\frac{d'M}{dt}+[\Omega, M] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Ω being the vector angular velocity. For C, however. we write

$$C=[H, \mathrm{m}] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and therefore from (2) and (3)

$$\frac{d'M}{dt}=[H, \mathrm{m}]-[\Omega,\ M]=[H, \mathrm{m}]-[2\frac{m}{e}\Omega,\ \mathrm{m}]=[H-2\frac{m}{e}\,\Omega, \mathrm{m}] \quad . \quad . \quad (4)$$

We are now dealing with the rotating system, and have no longer any relative rotation of H to consider. The expression (4) gives the couple acting on an elementary magnet in the rotating system, and we see that the equivalent field is given by $H-2\frac{m}{e}\bar{\Omega}$; $\bar{\Omega}$ is directed along the axis of rotation oz and is therefore perpendicular to $\bar{H}$. The vector $\bar{H}-2\frac{m}{e}\bar{\Omega}$ has a fixed direction in the plane $y'oz$, and makes an angle α with H such that $\alpha=\tan^{-1}\left(2\frac{m}{e}\cdot\frac{\Omega}{H}\right)$. In the rotating system the direction of

this vector will determine the axis of magnetization, and so there will be a transverse component parallel to the axis of rotation. The magnitude of the equivalent field does not differ appreciably from H; therefore, if I is the resultant intensity, the transverse component will be $I_z = I \cdot \sin\alpha = I \cdot \alpha = I \cdot 2\frac{m}{e} \cdot \frac{\Omega}{H}$, since α is small.

I/H is, however, the susceptibility k of the material, and so we have finally for the transverse magnetization

$$I_z = 2\frac{m}{e}\,\Omega k \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

To be sure the force at a point in the interior of a substance in a magnetizing field H is not H, but $H + \frac{4\pi}{3} I + X$, where I is the intensity of magnetization and X is the force due to the magnets in the immediate vicinity of the point under consideration. The latter vanishes in the case of fortuitous or regular cubic distributions of the elementary magnets,* and we may in any case, as a first approximation, write it proportional to I, so that the total force becomes $H + \left(\frac{4\pi}{3} + \beta\right) I$.

The justification for considering only the part H in the expression for the couple depends on the fact that the second component, being determined by the polarization I, has the same direction as I and consequently does not oppose a general rotation of the magnetic axis in the same sense. H is the only force independent of the orientation of the axes of the molecular magnets, and in the case under consideration H and I are no longer coincident but are inclined to one another at the angle α.

The effect being proportional to k it is clearly best to experiment with a material having a maximum possible value of k, *i.e.*, iron, and to work with fields for which k attains its greatest value. Precisely the same formula gives the intensity in Barnett's experiments on magnetization by rotation, but in this case the susceptibility k corresponds to small field strengths of the order $2\frac{m}{e}\,\Omega$, and is, therefore, according to the well-known curves for iron, considerably smaller than that corresponding to an external magnetizing field of the order of 1 Gauss or thereabouts, such as can be applied in the method described. From the results given by Barnett in one of his Papers† it appears that the susceptibility (including end effects) is about 5 for these small fields. We can, on the other hand, with field strengths of the order of 1 Gauss, easily reach values of k of 100—150, or, say 20 times as large, and herein lies the chief advantage of the above method. It possesses on the other hand a considerable disadvantage in that the large primary field can very easily give rise to strong fields very much greater than that due to the effect in question, and in the trials made I have not succeeded in eliminating these spurious effects with the apparatus which was available.

Experimental Tests.—In order to eliminate the stray fields as much as possible the rotating field was produced by two alternating currents differing in phase by 90° and exciting two suitably disposed electro-magnets, the specimen itself being a rectangular bar of soft iron passing between the pole-pieces of the magnets. In this case, theoretically at any rate, the mean value of the stray fields should be

* H. A. Lorentz, Theory of Electrons, p. 306.
† Barnett, Phys. Rev., VI., 1915, p. 270.

zero. It was sought to detect with a magnetometer a variation in the longitudinal magnetization of the rod, due to the effect in question, on changing the direction of rotation of the field, in which case the change in intensity of magnetization should be twice that given by the above formula.

It was, however, impossible to make any observations, as the irregular disturbances were at best about twenty times that of the effect looked for, and appeared to be due in almost equal measure to varying external fields and to variations in the alternating currents exciting the magnets. A couple of ancient single-phase alternators (frequency 50 ∽), coupled together with 90° phase difference, had to be used as generators, and the irregularities of the alternating currents followed, no doubt, from fluctuations of the exciting currents, which were derived from the mains, and to commutating action at the slip-rings due to bad contact and unevenness. No appreciable advantage was found to follow from fitting several brushes to each slip-ring. As the rectification of these deficiencies involved setting up the apparatus anew in a more favourable position and with a more suitable generator, the experiments had, at any rate for the time being, to be abandoned.

In conclusion, I wish to express my best thanks to Professor Richardson for his interest in the problem, and for the opportunity afforded to carry out the experiments in the Wheatstone laboratory.

DISCUSSION.

Dr. E. H. RAYNER alluded to the experimental difficulties occasioned by the distortion of the magnetic flux, owing partly to eddy currents in the iron bar and partly also to the non-uniform distribution of magnetic flux along the bar, only the middle section of which would be exposed to the magnetising field. The time-variation of the field-strength could be minimised by using a single alternator with polyphase windings and stationary armature, slip-rings being absent in this case from the magnetising circuits. An excellent machine of this kind belonging to the National Physical Laboratory might perhaps be placed at the Author's disposal.

Dr. L. SIMONS referred to some research he had seen last July being carried on in the Physics laboratory at Bristol. In this case an iron wire was hung vertically by means of a fibre fixed to its end. When a vertical magnetic field was put on, the wire experienced a momentary rotating couple. Elaborate precautions were necessary to eliminate disturbing factors such as lack of symmetry and electric trams which otherwise masked the effect under investigation. It seemed as though Mr. Fisher were looking for an effect of the same order of magnitude, and that consequently similar difficulties in the elimination of disturbing factors would arise.

Dr. D. OWEN inquired as to the magnitude of the effect to be observed. If it were large enough the errors could be suppressed by using a substance of lower permeability than iron, and preferably a non-conductor of electricity which would be free from eddy currents. It might then be of advantage to employ high-frequency fields, since the effect to be measured is proportional to the frequency.

Prof. O. W. RICHARDSON, replying on behalf of the author, thanked Dr. Rayner for his kind offer of a suitable alternator, of which advantage would be taken when time permitted. He thought that the effect of eddy currents had been fully considered by the author, although the latter had not mentioned the fact in his Paper. The experiments of Prof. Chattock and Mr. Bates, referred to by Dr. Simons, aimed to measure the rotatory mechanical impulse caused by magnetisation which Prof. Richardson attempted to detect experimentally, and made calculations about, in 1908. The effect which Mr. Fisher had sought to detect was of a somewhat more complex nature, but it was clearly a development of the same order of ideas. The use of higher frequencies, suggested by Dr. Owen, would accentuate the difficulties introduced by eddy currents, so that, in using conducting substances at any rate, there would be a certain optimum frequency at which to work. The magnitude of the effect would not be excessively small, though its measurement would be a delicate matter. Under the conditions referred to in the Paper it would be some 20 or 30 times as great as the effect detected by Barnett, which is the converse of the rotatory impulse effect due to magnetisation.

XXVI. *On the Viscous Properties and Molecular Dimensions of Silicane.* *By* A. O. Rankine, *D.Sc., Professor of Physics, and* C. J. Smith, *B.Sc., A.R.C.Sc., D.I.C., Research Student, Imperial College of Science and Technology, London.*

Received April 14, 1922.

ABSTRACT.

The absolute values of the viscosity of the gas silicane have been determined for the temperatures 15°C. and 100°C. The data have been used to calculate the mean collision area presented by the silicane molecule in the gaseous state. Use is then made of the knowledge of this dimension in an attempt to elucidate the structure of the silicane molecule in relation to those of other gaseous hydrides whose molecules have equal numbers of extra-nuclear electrons.

Silicane is a gaseous compound having the molecular composition SiH_4, thus resembling the well-known gas methane (CH_4). It is the last known member of a regular series commencing with argon and forming the sequence, argon, hydrogen chloride, sulphuretted hydrogen, phosphine and silicane—A, HCl, H_2S, PH_3, SiH_4. For each of these five molecules the "molecular number," *i.e.*, the sum of the atomic numbers of the various constituent atoms, is the same, namely, 18; and there are substantial grounds for believing that the central regions of all of them have practically the same dimensions, the differences in the mean collision areas of the complete molecules arising from external protruberances corresponding to the hydrogen atoms. The evidence for this is based mainly upon the results of the calculations of molecular size derived from the viscous properties of the first four gases of the sequence.* In order to extend the investigation as far as possible it was necessary to know corresponding dimensions for the silicane molecule, and we have therefore measured for this gas the necessary viscosity data.

Silicane is a gas not frequently made, and its preparation is attended with some difficulty. We have, however, succeeded, after some failures, in making a sufficient sample in a pure state by a method nearly the same as that described by Moissan.† Once prepared, silicane is quite stable, and there is no difficulty in measuring its viscosity with the same degree of accuracy as for the other gases previously mentioned.

Method of Observation.

The method which we have used to determine the viscosity of silicane at atmospheric and steam temperatures has already been described in detail.‡ It amounts to filling the viscometer with air, and then with the gas under investigation, and comparing the times taken for the same mercury pellet to drive equal volumes of gas through the capillary tube. This ratio, with appropriate corrections, gives the relative viscosities of air and the gas; and from it, assuming the absolute viscosity of air, that of the gas is deduced. For the variation with temperature, a knowledge of which is also necessary for estimating molecular dimensions, we compare the times of transpiration for the gas at atmospheric and steam temperatures.

* A. O. Rankine, Trans. Far. Soc., Vol. XVII., Part 3 (1922).

† Moissan, C. R., 134, p. 571 (1902).

‡ A. O. Rankine, and C. J. Smith, Phil. Mag., Vol. XLII., p. 601 (1921), and C. J. Smith, Proc. Phys. Soc., Vol. XXXIV., p. 155 (1922).

Preparation of the Silicane.

The sample of silicane was obtained by the action of hydrochloric acid on magnesium silicide—Mg_2Si. The purity of the magnesium silicide was tested spectroscopically by examining the spark spectrum in the ultra-violet region, when only magnesium and silicon were found to be present. The apparatus is shown diagrammatically in Fig. 1. The flask, *C*, contained 5 gm. of magnesium silicide. At first no liquids were present in the apparatus except strong sulphuric acid in the wash bottle, *A*. Commercial hydrogen, desiccated by bubbling through concentrated sulphuric acid, and then freed from possible traces of carbon dioxide and sulphur dioxide by circulation through a U-tube *B* in liquid air, was used to displace the air from the generating apparatus. When the air had been entirely displaced the flask *C* was surrounded by ice. This caused a sufficient reduction of pressure in the apparatus to enable 200 c.c. of water to be dropped into *C*, also some water into the scrubber *D*, and finally about 50 cc. of strong hydrochloric acid into *C*. The gas which is generated has been shown by Moissan (*loc. cit.*) to consist of two hydrides of silicon—SiH_4 and Si_2H_6—and a large excess of hydrogen. (This mixture is spontaneously inflammable when brought in contact with air—a fact which necessi-

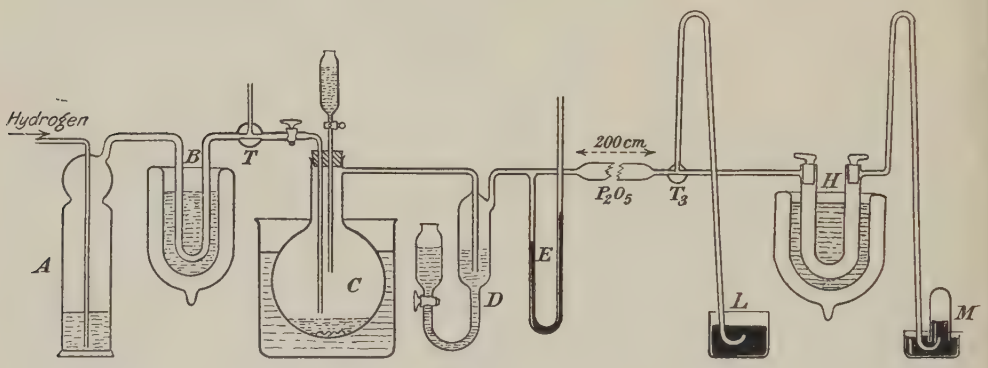

FIG. 1.

tates the exclusion of air from the generating apparatus in the manner described.) The mixed gases were freed from traces of hydrogen chloride by being bubbled through the water in *D*, and dried by being passed through tubes—200 cm. long—containing phosphorus pentoxide. Ultimately the silicon hydrides were solidified in a U-tube *H* surrounded by liquid air. The stream of hydrogen was kept bubbling through *A* throughout the process; when not required in *C* it was diverted by means of the three-way tap *T*. The pressure gauge *E* was inserted to detect whether any blocking up took place in the apparatus.

When sufficient solid had collected in *H*, the three-way tap T_3 served to cut off *H* from the rest of the apparatus, and also provided an alternative escape through *L* for the gases still being generated. The liquid air around *H* was then replaced by alcohol cooled to —80°C. by means of solid CO_2. This temperature is well above the boiling point of silicane, which thus evaporated. The escaping gas was collected over mercury at *M*, and consisted of a mixture of hydrogen and silicane, rich in the latter constituent.

Before introduction to the viscometer the silicane was purified by fractional

distillation. It was condensed at liquid air temperature, and the permanent gases, mainly hydrogen, were pumped off. The liquid air was then removed and alcohol and CO_2 at —80°C. substituted. This retained possible traces of water and silicoethane (Si_2H_6) (which boils at a comparatively high temperature well above 0°C.), and allowed the purified silicane to evaporate and be collected. This same process was repeated twice before measurements with the gas were commenced.

After the observations had been made the gas in the viscometer was found to be wholly condensible at liquid air temperature. The purity of the silicane was thereby confirmed.

Results.

Dry Air.

The air which was used for comparison was dried by being passed over phosphorus pentoxide, and then through a tube maintained at —80°C. by means of solid CO_2 and alcohol, before being introduced into the viscometer. Three sets of observations in the neighbourhood of 15·0°C. were made, the results being consistent to within 0·1 per cent. The mean time of fall corrected to 15·0°C. was 104·70 secs.

Silicane.

Table I.

	Temp. (°C.)	Time of fall (secs.)		Capillary correction (x)	Corrected time (t)	Time of fall.	
		Whole pellet.	Two segments			15·0°C.	100·0°C.
(*a*)	15·3	69·06	72·18	0·0413	66·21	66·15	...
(*c*)	15·9	69·54	73·17	0·0473	66·25	66·06	...
					Mean	66·11	...
(*b*)	99·5	85·60	87·70	0·0234	83·60	...	83·70

The order in which the observations were made is shown by the letters in the first column. Each figure recorded in Column 3 is the mean of eight observations, mutually consistent to within 0·6 per cent., and those in column 4 the mean of six, mutually consistent to within 0·4 per cent.

In the above table small corrections have been made to reduce the observations to the standard temperatures 15·0°C. and 100·0°C.

The ratio of the times of fall for silicane and air at 15·0°C. is thus

$$\frac{t_{SiH_4}}{t_{Air}} = \frac{66{\cdot}06}{104{\cdot}70} = 0{\cdot}6314$$

Correcting for slip in the manner previously indicated,* this ratio becomes 0·6304, whence, on the basis that the viscosity of air at 15·0°C. is $1{\cdot}799 \times 10^{-4}$ C.G.S. units, we have for silicane

$$\eta_{15} = 0{\cdot}6304 \times 1{\cdot}799 \times 10^{-4} = 1{\cdot}134 \times 10^{-4} \text{ C.G.S. units.}$$

Also

$$\frac{\eta_{100}}{\eta_{15}} = \frac{t_{100}}{t_{15}} = \frac{83{\cdot}70}{66{\cdot}11} = 1{\cdot}266$$

whence for silicane

$$\eta_{100} = 1{\cdot}436 \times 10^{-4} \text{ C.G.S. units.}$$

If we assume that Sutherland's law holds for the gas silicane over the range of

* A. O. Rankine, Proc. Roy. Soc., A. Vol. LXXXIII., p. 517.

temperature used in these experiments, we obtain for silicane $C=229$, where C is Sutherland's constant. Extrapolating to 0·0°C. we get

$$\eta_0 = 1{\cdot}078 \times 10^{-4} \text{ C.G.S. units.}$$

Calculation of Molecular Dimensions.

The mean area presented for collision by molecules of silicane in thermal agitation may be calculated by means of Chapman's formula, interpreted in the way already frequently described.* The result obtained is

$$\bar{A} = 0{\cdot}989 \times 10^{-15} \text{ cm.}^2.$$

Comparing it with the corresponding area for the argon molecule, namely, $0{\cdot}648 \times 10^{-15}$ cm.^{2}, we find

$$\frac{\bar{A}_{\text{ silicane}}}{\bar{A}_{\text{ argon}}} = \frac{0{\cdot}989}{0{\cdot}648} = 1{\cdot}53.$$

Summary of Results for Silicane.

Viscosity in C.G.S. units $\times 10^{-4}$			Sutherland's Constant C.	Mean collision area of molecule $\bar{A}$.
15°C.	100°C.	0°C.		
1·134	1·436	1·078	229	$0{\cdot}989 \times 10^{-14}$cm.^{2}

Discussion of Results.

Attention has already been called† to the probable relation between the structures of the five gaseous molecules which form the sequence—

SiH_4 PH_3 H_2S HCl A

Any member of the sequence can be regarded as a system in which the stable configuration of extra-nuclear electrons of the argon atom has been attained by the addition of a sufficient number of the single electrons of hydrogen atoms, the nuclei of the latter remaining external to the system. In SiH_4, for example, four additional electrons are required for this purpose, the atomic number of silicon being four less than the argon number ; thus four hydrogen atoms are needed to complete the stable molecule. Reasons based on crystal measurements have already been adduced† for believing that there are no appreciable differences of effective size of the completed electron configurations, and for attributing any variation of apparent magnitude in the above molecules to the effect of protuberances corresponding to the nuclei of the attached hydrogen atoms. Certainly the mean collision areas of the molecules continue to increase as we pass from argon to phosphine, and the new data available for SiH_4 show that this molecule is no exception to the rule. The numerical values for the mean collision areas, shown as ratios to that of argon, are

SiH_4	PH_3	H_2S	HCl	A
1·53	1·41	1·19	1·04	1·00

and these results are also shown graphically in Fig. 2, where the absolute mean

* A. O. Rankine and C. J. Smith, Phil. Mag., Vol. XLII., p. 612, Nov., 1921 ; and A. O. Rankine, Proc. Phys. Soc., Vol. XXXIII., p. 362 (1921).

† A. O. Rankine, Trans. Faraday Soc., Vol. XVII., Part 3 (1922).

collision areas are plotted against the number of hydrogen atoms in the molecule. The dotted line is not intended to denote continuity, for the number of hydrogen atoms must obviously be integral, but merely to emphasise the relative magnitudes of the successive increments.

It will be noticed that although the increments increase more and more rapidly in passing from argon to phosphine, the newly determined increment from PH_3 to SiH_4 is of smaller magnitude than the two previous steps. It is suggested that the explanation of this result is to be found in a combination of two effects which operate in opposite senses.

The fact that at first the successive increments increase with each addition of a hydrogen atom is consistent with the view already put forward that the protuberances for which the hydrogen nuclei are responsible grow with increasing number. This growth may very plausibly be attributed to the retreat from one another of the

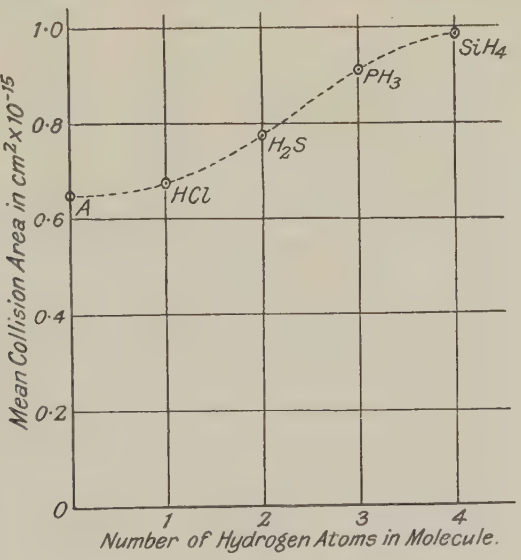

FIG. 2.

hydrogen nuclei which occupy the outskirts of the molecule, on account of their increasing mutual repulsion. Thus, if we suppose that the contributions of each hydrogen protuberance to the mean collision area are independent of one another, we should expect the graph in Fig. 2 to display an upward curvature throughout. But if the prominences are large enough and numerous enough it is improbable that the contributions would be thus independent.

Let us picture the molecule for purposes of collision as a hard central sphere of the argon size, having a certain number of prominences corresponding to the hydrogen atoms. The area which the molecule will present as a target for any given orientation will depend upon the degree of mutual overlapping of the projections of the central sphere and the prominences. In the case of HCl, where there is only one prominence, there can be no question of mutual eclipses of prominences themselves, as distinct from eclipses of prominences by the central sphere. The comparative mean collision areas of HCl and A are 1·04 and 1·00, and we may therefore regard the excess 0·04 as the contribution of the single hydrogen prominence.

In the next molecule, H_2S, we have two hydrogen prominences which, for reasons of symmetry, we may expect to be on opposite sides of the central sphere. In these positions they also will be unable to eclipse one another except when already overlapped by the central sphere. Thus each will make an independent contribution to the mean collision area, the amount of each being $\frac{1}{2} \times 0{\cdot}19 = 0{\cdot}095$ times the mean collision area of argon. The excess of 0·095 over 0·04 may be taken as indicating precisely that each hydrogen protuberance in H_2S is greater than the single one in HCl.

When we come to PH_3, however, we can no longer assume that the effect of overlapping prominences is zero. There are now three prominences distributed round the central sphere, and if they are large enough there will obviously be certain orientations of the molecule in which mutual eclipsing of prominences occurs in which the central sphere plays no part. The effect of this will be to reduce the value of the mean collision area, and thereby to diminish the effect of any enlargement of the protuberances which may have occurred in passing from H_2S to PH_3. Actually, in spite of this, the increment between H_2S and PH_3 is larger than that between HCl and H_2S (0·22 as compared with 0·15). The effect of multiple overlapping is, apparently, in this case insufficient to obscure completely the enlargement of the protuberances.

In SiH_4 the prominences are four in number, and the operation of the kind of overlapping referred to in the last paragraph may be expected to be much more marked on this account. A little consideration shows that in the limit, when the number of prominences becomes very large, a single additional one of the same magnitude, which does not give rise to any general enlargement of those already there, may be inserted without increasing appreciably the mean collision area of the molecule. The fact, therefore, that there is so considerable an increase (0·12) between PH_3 and SiH_4 is not inconsistent with the view that the hydrogen prominences in the latter molecule are still greater in size, and that their growth has been masked to a considerable extent in the manner indicated.

Since we have not at present sufficient information to enable us to assign a probable shape to the prominences, the matter cannot be treated quantitatively; but qualitatively the new data for the silicane molecule support the conclusions already deduced from previously known data, namely (*a*) that these hydrogen compounds have central regions of configuration nearly identical with that of an argon atom, and only differ in dimensions by reason of the outlying hydrogen nuclei; and (*b*) that the distances of the hydrogen nuclei from the centre of the molecule increase more and more rapidly as the nuclei multiply.

DISCUSSION.

Prof. O. W. Richardson: Am I right in understanding that the authors' results conflict with those obtained by X-ray measurement of crystal lattices?

The Authors: The conflict to which Prof. Richardson has referred is apparent rather than real. The only point of contact between the two methods is afforded by the inert gases, the crystallographic diameters of whose atoms can be extrapolated from those of other elements in the same series. Thus Cl and O are found by Sir W. H. Bragg to have nearly the same diameters, and it is assumed from continuity that the diameter in argon agrees with these. The diameters found by the present method are somewhat larger, but the dimensions to be measured are not the same in the two cases. It must be assumed not that the atoms have hard shells which impinge on one another, but rather that they approach one another up to the distance at which the force between them changes sign and becomes a repulsion. This distance, being larger than the radius of the outer electron system, gives a different figure from that obtained by crystal measurements.

XXVII. *The Pressure-Gradient in Liquids Flowing Through Cones.*

By W. N. Bond, *B.Sc. (Eng.), M.Sc. (Lond.), Lecturer in Physics, University College, Reading.*

Received May 1, 1922.

ABSTRACT.

The pressure gradient in a liquid that flows through a conical tube is considered as depending on three effects: the variation in kinetic energy with distance along the axis; the loss due to purely viscous flow; and the loss caused by eddying. Expressions are developed giving approximately the gradient due to the three effects independently. The independence of the effects due to varying velocity and to "losses" is assumed as a working hypothesis. It is hence shown that these two effects should be capable of determination by two sets of experiments on any chosen cone, the direction of flow being reversed in the second experiments.

The effect of the entrance conditions is discussed.

The results of experiments on three ambroid cones of semi-angles $15\frac{1}{2}'$, $1°51'$ and $4°2'$ respectively are given. The conicality and losses effects are deduced, and these are plotted, the values for all the cones being reduced to a common basis. The results are compared with the theoretical values, experiments on a parallel ambroid tube and Stanton's experiments on parallel tubes of drawn brass. Two interesting conditions are mentioned, and a peculiarity is found in the case of divergent flow at moderate speeds through the cones of larger semi-angle.

Introduction.

The present Paper consists of an attempt to extend the knowledge relating to the flow of liquids through conical tubes of circular cross-section by investigating how the pressure gradient along the walls of the tube is related to the rate of flow of the liquid and to the other variables concerned. For previous work on the subject, reference may be made to Chapters III. and IV. of "Gibson's Hydraulics," 1919.

Conical pipes were chosen, in order to make the shape easy to specify and also to facilitate as complete a theoretical treatment as possible. The restriction of the work to liquids enables variation in density to be neglected, but viscosity and density must be considered in these and any similar experiments.

General Theory of Pressure Gradient.

General equations may be obtained from the theory of dimensions before proceeding to more detailed theories.

Consider a right circular cone of semi-angle α. Let dp/dl denote the variation in pressure at the boundary with distance measured in the direction of flow, parallel to the axis; the radius of the circular section at this point being Υ.

(All pressure differences due to actual difference of level are for convenience throughout supposed to have been deducted.)

Let Q=volume of liquid passing in unit time (cm^3/sec).
ρ=density of liquid.
μ=viscosity of liquid.

Then we have

$$dp/dl=Q^2\rho/\Upsilon^5 . f_1(Q\rho/\Upsilon\mu, \alpha)=Q\mu/\Upsilon^4 . f_2(Q\rho/\Upsilon\mu, \alpha). \quad . \quad . \quad . \quad (I)$$

Detailed Theory of Pressure Gradients.

Three main factors which affect the pressure gradient have to be considered. Firstly, differences of pressure due to the variation of the velocity and kinetic energy of the liquid with the distance along the cone. Secondly, losses of pressure due to purely viscous flow. And thirdly, losses due to eddying and hence indirectly to viscosity.

The pressure gradient due to variation in kinetic energy depends on how the velocity varies across any transverse section, and may be obtained on the supposition that the velocity has a value v which is constant over any sphere of radius R described with the apex of the cone as centre. For a diverging cone the pressure gradient due to conicality alone is given by

$$\frac{dp}{dR} = -\frac{\rho}{2} \cdot \frac{d(v^2)}{dR}$$

or

$$\frac{dp}{dl} = \frac{\sin^4\alpha}{2\pi^2(1-\cos\alpha)^2} \cdot \tan\alpha \cdot \frac{\rho Q^2}{\Upsilon^5}$$

$$\longrightarrow \left.\begin{array}{l} 2\alpha\,\rho Q^2/\pi^2\Upsilon^5 \text{ for small values of } \alpha, \\ \text{with an error of under 1 per cent. for } \alpha = 10^\circ \end{array}\right\} \quad \ldots\ldots \quad \text{(II.)}$$

If the velocity across any transverse section be assumed to vary in the way it is found to do for turbulent flow in straight pipes, a similar theory gives a value about 12 per cent. larger than Equation (II.). This value has been verified experimentally. (For references, *see* Lea's "Hydraulics," 1916, p. 147.)

The calculation of the pressure gradient for the case of purely viscous flow, the author finds has been given by W. J. Harrison,* so it need only be given briefly, with application to the present problem. Since the lines of flow are straight lines passing through the apex of the cone, we have

$$v = \varphi(\theta)/R^2$$

where R, θ are the polar co-ordinates of the point.

Then, using the general hydrodynamical equations in which the terms depending on kinetic energy are neglected, we obtain

$$\varphi''' + \varphi'' \cot\theta + \varphi'(6 - \operatorname{cosec}^2\theta) = 0.$$

Hence

$$\varphi = C(\cos 2\theta - \cos 2\alpha)$$

and

$$\left(\frac{dp}{dR}\right)_{\theta=\alpha} = -\frac{Q\mu}{R^4} \cdot \frac{3}{\pi} \cdot \frac{3\cos^2\alpha - 1}{2\cos^3\alpha - 3\cos^2\alpha + 1}$$

or

$$\frac{dp}{dl} = -\frac{3}{\pi} \cdot \frac{\sin^4\alpha(3\cos^2\alpha - 1)}{\cos\alpha(2\cos^3\alpha - 3\cos^2\alpha + 1)} \cdot \frac{Q\mu}{\Upsilon^4}$$

$$\longrightarrow \left.\begin{array}{l} -8Q\mu/\pi\Upsilon^4 \text{ for small values of } \alpha \\ \text{with an error of under 4 per cent. for } \alpha = 10^\circ \end{array}\right\} \quad \ldots\ldots \quad \text{(III.)}$$

Thus, in this case, the pressure gradient at any point is to a close approximation the same as if the tube were of the same diameter but parallel. For cones of small angle an expression was previously derived by Gibson,† which gives the same result for such angles as the limiting value given in Equation (III.) above.

* Proc. Camb. Phil. Soc., Vol. XIX., pp. 311-12.

† Phil Mag., 18, 1909, p. 38.

When the flow is almost purely viscous, the velocity variation across any transverse section is approximately parabolic, and hence the small pressure gradient due to differences of kinetic energy (which may be supposed superposed on the gradient due to viscous forces) may be deduced. Thus, for a diverging cone, we have approximately

$$Q\frac{dp}{dR}=-\int_0^{\Upsilon}\tfrac{1}{2}\rho(2\pi\Upsilon\,.\,d\Upsilon)v\frac{d(v^2)}{dR}$$

or

$$dp/dl=4\alpha\,\rho Q^2/\pi^2\Upsilon^5 \text{ (approximately)} \quad . \quad . \quad . \quad . \quad \text{(IV.)}$$

Thus the gradient due to conicality has under these conditions about double the value it has when the velocity is approximately constant over any transverse section.

The loss of pressure due to turbulence is supposed to depend on the nature of the boundary ; and there is considerable evidence that it depends on the condition under which the liquid enters the tube.*

In experiments on parallel pipes it is usual to let the liquid pass through a considerable length of similar pipe before it reaches the section experimented on. It is not possible to extend a diverging cone in this manner, since it is limited in the upstream directions by its apex. Hence it is necessary to make the liquid enter a diverging cone from a parallel or converging section, the transition being made as gradual as possible.

The pressure gradient due to turbulence may depend on the angle of the cone besides on the other variables. Since no data are available in regard to this effect, we may assume that, as in the case of a parallel pipe, the pressure gradient due to eddying may be represented by

$$dp/dl=A\,\rho Q^2/\Upsilon^5+B\,\rho^{1-n}\mu^n Q^{2-n}/\Upsilon^{5-n} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(V.)}$$

There A, B and n are positive constants, depending on the nature of the surface roughness.†

It is interesting to notice that Stanton‡ found experimentally that the pressure losses for different diameters of parallel pipe of the same material were in the same ratio as would have been expected had the linear dimensions of the roughness been made proportional to the diameter of the pipe. Since such geometrical similarity of roughness probably did not exist, it follows that the absolute magnitude of the roughness is of little importance, provided the roughness be small. Hence the roughness can only influence the eddy losses in virtue of the nature of its contour.

Reversible and Non-reversible Effects.

Throughout this Paper the pressure gradient is termed positive when the pressure increases on passing down the tube in the direction of motion. Adopting this convention, it will be seen that the gradient due to " losses " is always negative, but that due to varying diameter or conicality is positive for diverging and negative for converging cones. If these effects act approximately as if independent, experiments on any cone with flow first in one direction and then in the reverse, should give values

* L. Schiller, Zeits. Math. u. Mechanik, Vol. I., No. 6, pp. 436-444.
† Lees, Proc. R. Soc., A., Vol. XCI.
‡ Stanton and Pannell, Phil. Trans., A., Vol. CCXIV., p. 299.

of the two effects separately. This is assumed as a working hypothesis, and may be considered in conjunction with the experimental results given below.

Since for purely turbulent flow the eddy loss is roughly proportional to the square of the rate of flow, it may be seen that it is probably not feasible to separate these two effects by means of experiments on cones of the same angle but of different diameters, since the two effects vary almost in proportion.

For divergent cones two effects in particular are of interest. Firstly, for any angle of cone, there is a critical condition when the gradient due to viscous loss is just neutralised by that due to divergence, and there is thus zero pressure gradient at the point. Secondly, for very high speeds there is some angle depending on the roughness of the walls, for which the eddy loss is approximately neutralised by the divergent gain. The semi-angle would be of the order of four minutes.

Deduction of the Pressure Gradient from Observed Pressure Differences.

Since in these experiments the difference in pressure between two points is observed, account must be taken of the fact that the radius Υ of the circular section varies continuously between the two pressure holes.

Consider the extreme cases in which Equation (I.) may be written

$$dp/dl = a\,\rho Q^2/\Upsilon^5 \text{ and } b\mu Q/\Upsilon^4,$$

where a and b are constant. The observed pressure difference δp between points separated by a distance δl along the axis is given by

$$\delta p/\delta l = a\,\rho Q^2[1/\Upsilon^4]/4[\Upsilon] \text{ and } b\mu Q[1/\Upsilon^3]/3[\Upsilon]$$

in the two cases. Hence, the pressure gradient is given in the two cases by

$$\frac{dp}{dl} = \frac{4[\Upsilon]}{\Upsilon_m{}^5[1/\Upsilon^4]} \cdot \frac{\delta p}{\delta l} \text{ and } \frac{3[\Upsilon]}{\Upsilon_m{}^4[1/\Upsilon^3]} \cdot \frac{\delta p}{\delta l} \quad \text{(VI.)}$$

at a point where the radius is Υ_m. This may for convenience be chosen as the mean of the radii at the pressure holes.

The results obtained by these two extreme suppositions do not differ much in the present experiments.

The first part of Equation (VI.) is therefore used, since it is nearly correct for large rates of flow, and only causes in the case of one cone at the very lowest speeds an error of about 10 per cent. In all other cases the error is quite negligible.

Experiments.

Small ambroid tubes were used for the experiments. These are shown in section in Fig. 1. The inside was cut to a conical form of the desired angle by means of suitable rimers, care being taken to make the deviation from the conical boundary at the narrow end a gradual curve. Small holes were drilled in the walls at chosen positions and a pair of holes was connected by tubes to a manometer. A simple water manometer, water over mercury, paraffin over water " U " tubes, and inclined tube water manometers were used. The liquid passed through the tube was water, except in a few experiments where mixtures of glycerine and water were used. An upper limit to the rate of flow practicable was set by the gases dissolved in the water being evolved at points of low pressure.

To minimise this trouble the cone was inclined so that the side holes were below, and the liquid emerged at the upper end. Thus any bubbles were quickly removed by the moving liquid and did not get into the manometer tubes.

The tubes were measured with travelling microscopes both in their complete form (the tubes being transparent) and also after being cut transversely at the pressure holes.

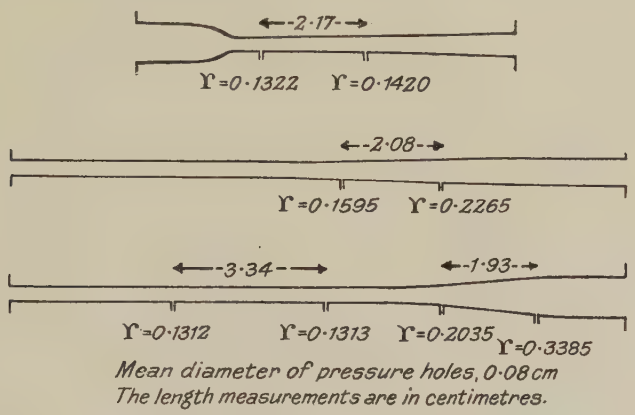

FIG. 1.

In plotting the results of experiments on each tube it has been found most convenient to draw a graph relating h/Q and Q, where h is the excess of the pressure

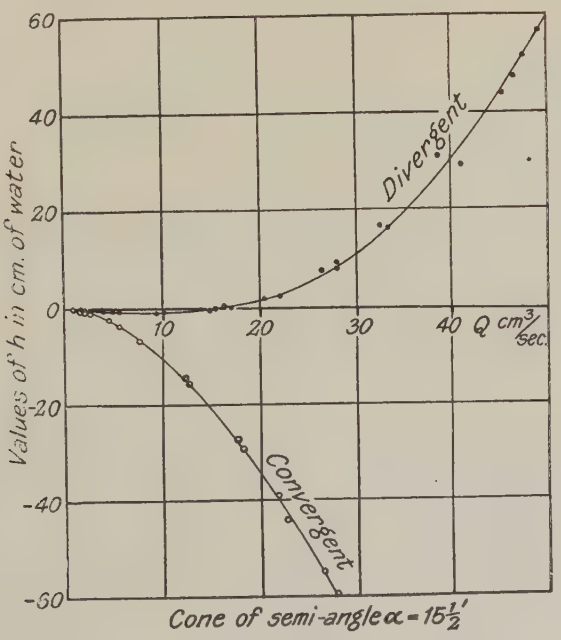

FIG. 2

at the down-stream pressure hole over that at the hole further up stream, measured in centimetres of water.

Fig. 2 shows the (h, Q) curve for the cone with semi-angle $\alpha=15\frac{1}{2}'$, and it will

be seen that for the divergent case there is a point at which the viscous loss and the kinetic gain combine to give zero pressure difference.

Fig. 3 shows the (h/Q, Q) curve for the same experiments. It will be seen that for small rates of flow the curves approximate to a constant value, due to viscous loss. For large rates of flow the curves approximate to straight lines through the origin, and hence to the condition $h \propto Q^2$.

The dotted curve with its ordinates the mean of those in the two original curves should, according to our supposition, represent the pressure gradient due to losses. The difference between the ordinate of this curve and that of either of the original

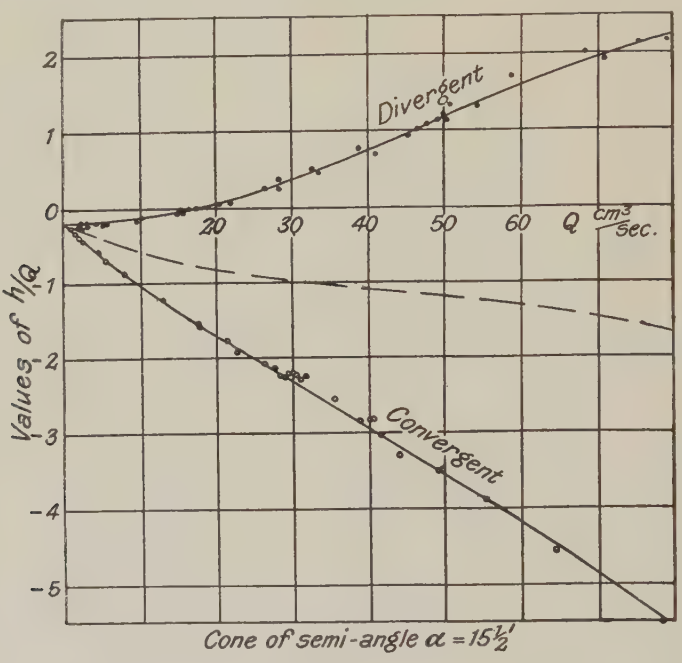

FIG. 3.

curves should represent the gradient due to varying kinetic energy (*i.e.*, due to conicality).

Figs. 4 and 5 show similar curves for the cases when $\alpha = 1°51'$, and $\alpha = 4°2'$. In Fig. 5 the mean curve is almost along the axis, and cannot claim to the least accuracy. It will be seen that the ratio of the effects due to eddy losses and to conicality decreases considerably as α is increased, varying in the case of the present experiments from about 50 to 1/50. The curves in Figs. 3 to 5 all reach a small negative value when $Q \longrightarrow O$, due to the existence of purely viscous losses.

In Figs. 4 and 5 the curves for the experiments on divergent cones show a marked peculiarity after h/Q attains a positive value and before Q becomes very large. This irregularity is peculiar to the divergent cones of not very small angle, and hence the " mean " curve in Fig. 4 has been drawn as in Fig. 3, the peculiarity of the curve for diverging flow being ignored. This is equivalent to the supposition that the peculiarity is due to some effect of conicality and is confined to the diverging case.

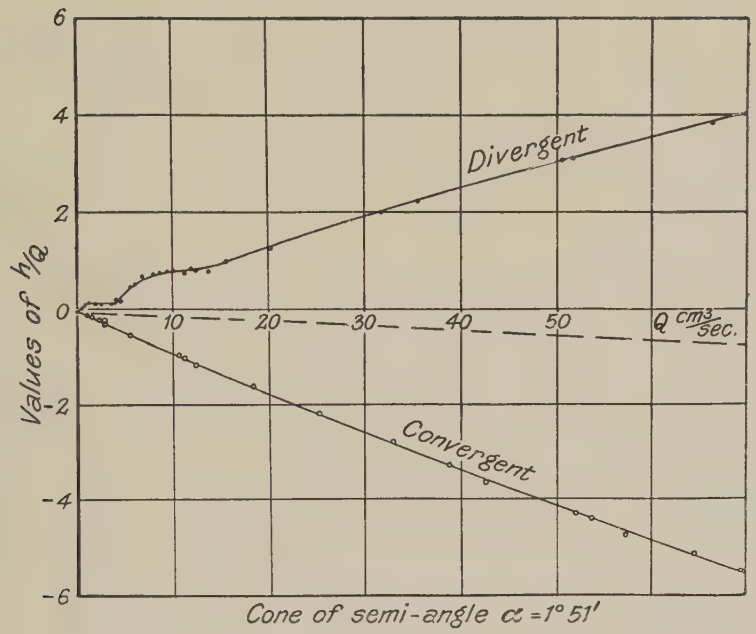
6
4
2
0
-2
-4
-6
Values of h/Q
Divergent
Convergent
10
20
30
40
50
Q cm³/sec.
Cone of semi-angle α = 1° 51′

FIG. 4.

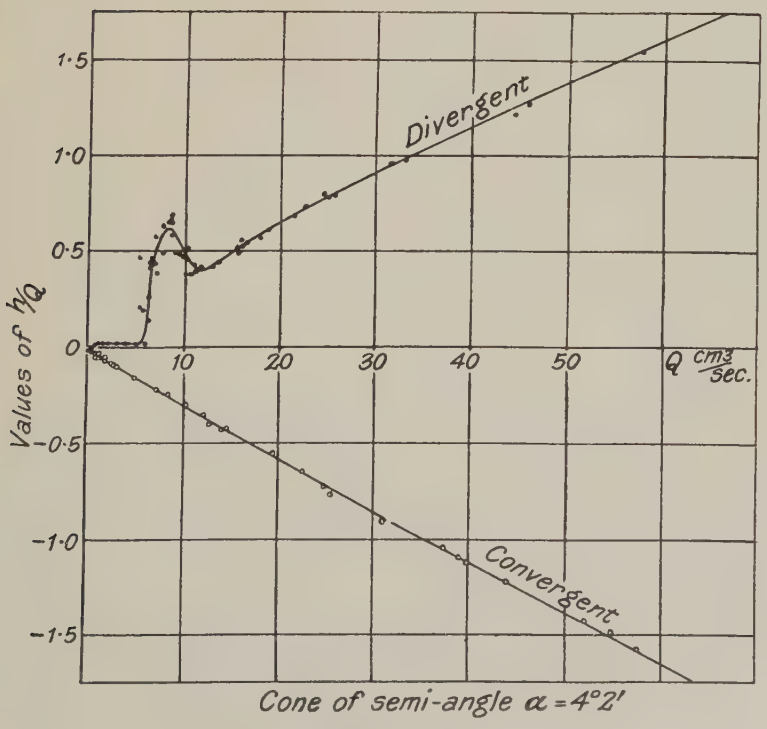
1·5
1·0
0·5
0
-0·5
-1·0
-1·5
Values of h/Q
Divergent
Convergent
10
20
30
40
50
Q cm³/sec.
Cone of semi-angle α = 4° 2′

FIG. 5.

In order to reduce the experiments to a common basis, we may apply an equation of the form of Equation (I.), first, to the effect of conicality treated alone. If squares of the angle of the cone be neglected, which we see by Equations (II.) and (IV.) is legitimate, we have

$$(\Upsilon^5/\alpha Q^2\rho)dp/dl \text{ a function of } Q\rho/\Upsilon\mu \text{ only.} \quad . \quad . \quad . \quad . \quad \text{(VII.)}$$

which, according to Equation (I.), tends approximately to the limit $\pm 2/\pi^2$ or $\pm 0{\cdot}203$ for large values of $Q\rho/\Upsilon\mu$, and according to equation (IV.) should tend to double this limiting value for very small values of $Q\rho/\Upsilon\mu$.

This expression (VII.) evaluated from the observations with the aid of Equation (VI.) is plotted against values of $Q\rho/\Upsilon\mu$ in Fig. 6. For the larger angles of cone two curves are drawn in the neighbourhood of the peculiarity, one being obtained from the convergent and one from the divergent experiment. For large

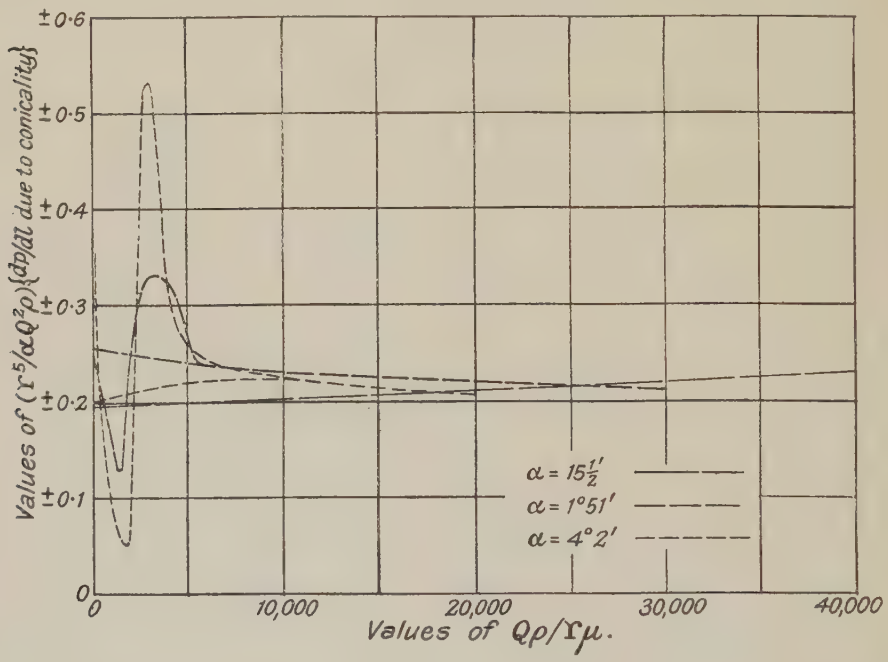

FIG. 6.

values of $Q\rho/\Upsilon\mu$ the curves agree with the limit mentioned above, $(2/\pi^2)(1{\cdot}12) = 0{\cdot}227$. For low values the ordinate does not attain the value $4/\pi^2$, but it is possible that if the experiments had been extended to lower values of Q this limit might have been reached. A Paper read to this Society by Prof. Hemmy* should yield information on this point, but he does not state whether his experiments were on a diverging or a converging cone. Since the peculiarity of the divergent case is not proportional to α, it is probably due to the initial condition of the liquid entering. The liquid may, over this range, perhaps flow for some distance in a narrow diverging stream near the centre of the tube, leaving the surrounding liquid comparatively at rest.

* Prof. A. S. Hemmy, Proc. Phys. Soc., Vol. XXXIV, Dec., 1921, p. 22.

Again applying an equation of the form of Equation (I.) to the gradient due to viscous and turbulent losses treated apart from the conicality effect, we have

$$(\Upsilon^4/Q\mu)dp/dl \text{ a function of } Q\rho/\Upsilon\mu \text{ alone} \quad . \quad . \quad . \quad . \quad . \quad \text{(VIII.)}$$

with the limiting value for small values of the latter of $-8/\pi = 2{\cdot}55$ (by Equation III.).

This expression (VIII.) may be plotted with the aid of Equation (VI.), and is given in Fig. 7.

Curves are also plotted in this figure, obtained from experiments on the parallel pipe shown in Fig. 1. The pipe was tested with flow in each direction, and the difference in the results could not be accounted for by difference in diameter at the two pressure holes. It is thus probably due to the difference in initial conditions of the liquid depending on the shape of the entrance. The importance of this effect on the eddy losses, and the impossibility of a long up-stream to a diverging

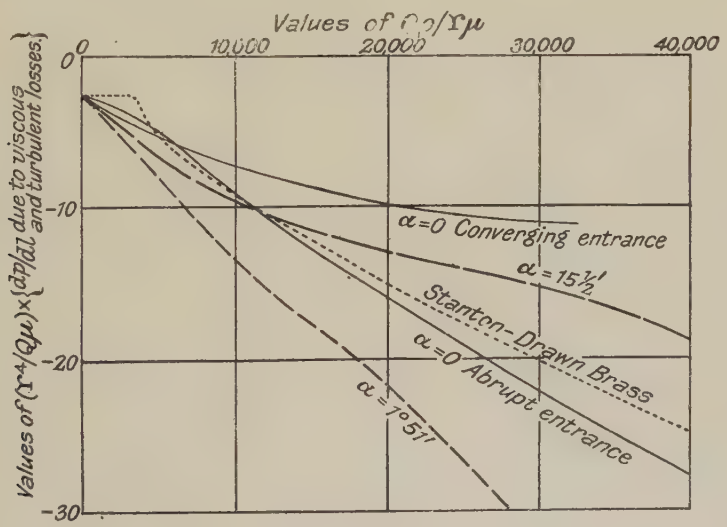

FIG. 7.

cone, must be remembered. A curve is also plotted in Fig. 7 obtained from Stanton and Pannell's experiments (*loc. cit.*) on drawn brass tubes.

All the curves reach values very close to $-8/\pi$ for small rates of flow. The present experiments do not, however, give a stable viscous flow over so big a range as is found for long parallel tubes. This is probably due to the impossibility of the same up-stream conditions. The eddy losses, which depend on the roughness, are not constant.

Since the hypothesis of reversability leads to values of $(\Upsilon^5/aQ^2\rho)dp/dl$ that agree with previous independent estimates, it must be concluded that the mean curve in Figs. 3 and 4 represents the effect of the losses with a fair amount of accuracy. Hence the losses are approximately the same whether the cone be a converging or a diverging one. From these considerations and a comparison of the values of the losses effect in all the present experiments, it may be concluded that the losses term is not affected to any large extent by the angle of the cone.

The difference between the various curves in Fig. 7 can, however, easily be accounted for by differences of entrance conditions (the effect of which was considered above) and difference in roughness of the different tubes. The large effect of tubes having different surface roughness may be seen by reference to Stanton and Pannell's paper (*loc. cit.*).

Hence it is seen that for cones of small and moderate semi-angle, the hypothesis of the approximate independence of the conicality and losses effects is confirmed. For this hypothesis, together with that relating to the reversibility of the effects, leads to estimates of the values of the two effects which are self-consistent and in agreement with other theoretical and experimental estimates.

In conclusion, the author would like to thank Prof. W. G. Duffield for the facilities that have enabled this investigation to be carried out, and Mr. J. S. Burgess for his kind help throughout the course of the experiments.

DISCUSSION.

Dr. H. CHATLEY remarked that the irregularity in the curves of Fig. 6 appeared to be greatest in the neighbourhood of 5 deg., a fact which suggests analogy with the drift angle of aerofoils. A similar phenomenon is dealt with in Gibson's Hydraulics.

Mr. R. S. WHIPPLE thought it would be interesting to indicate the lines of flow by means of colouring matter, as was done by Prof. Hele-Shaw, and to project an image of them on to a screen.

The AUTHOR, in reply, said that whereas Dr. Gibson mentions a critical angle of 5 deg., the irregularity referred to by Dr. Chatley seems to take place more or less at all angles, at much the same rate of flow. It must be noted, however, that all the tubes had the same diameter at the narrow end. It would certainly be interesting to use colouring matter, as this would indicate whether, at the speeds at which the irregularity occurs, there is a stream down the middle of the tube which breaks away from the remainder of the liquid.

List of Elements and Their Isotopes. *By* F. W. ASTON, *M.A., D.Sc., F.R.S.*

GIVEN in course of a lecture delivered before the Society on May 26, 1922.

Table of Elements and Isotopes.

Element.	Atomic Number.	Atomic Weight.	Minimum number of Isotopes.	Masses of Isotopes in order of intensity.
H	1	1·008	1	1·008
He	2	3·99	1	4
Li	3	6·94	2	7, 6
Be	4	9·1	1	9
B	5	10·9	2	11, 10
C	6	12·00	1	12
N	7	14·01	1	14
O	8	16 00	1	16
F	9	19 00	1	19
Ne	10	20·20	2	20, 22, (21)
Na	11	23·00	1	23
Mg	12	24·32	3	24, 25, 26
Si	14	28·3	2	28, 29, (30)
P	15	31·04	1	31
S	16	32·06	1	32
Cl	17	35·46	2	35, 37, (39)
A	18	39·88	2	40, 36
K	19	39·10	2	39, 41
Ca	20	40·07	(2)	(40, 44)
Ni	28	58·68	2	58, 60
Zn	30	65·37	(4)	(64, 66, 68, 70)
As	33	74·96	1	75
Br	35	79·92	2	79, 81
Kr	36	82·92	6	84, 86, 82, 83, 80, 78
Rb	37	85·45	2	85, 87
I	53	126·92	1	127
X	54	130·2	5 (7)	129, 132, 131, 134, 136, (128), (130 ?)
Cs	55	132·81	1	133
Hg	80	200·6	(6)	(197-200), 202, 204

(Numbers in brackets are provisional only).

XXVIII. *On Whittaker's Quantum Mechanism.* *By* H. Stanley Allen, *M.A.*, *D.Sc., Reader in Physics in the University of Edinburgh.*

Received June 5, 1922.

ABSTRACT.

A brief description is given of the mechanism of Prof. E. T. Whittaker which compels all exchanges between the kinetic energy of electrons and radiant energy to conform to the quantum condition. A modified form of the mechanism is suggested, consisting of two magnetons, or two ring electrons, placed near together with their planes parallel. It is pointed out that the quantum mechanism gives the law of force postulated by Langmuir in his model of a static atom, which leads to results identical with those obtained from the circular orbits of Bohr's theory.

§1. In a suggestive Paper read before the Royal Society of Edinburgh on 8th May 1922, Prof. E. T. Whittaker has described a mechanism within the atom so constituted as to compel all exchanges between the kinetic energy of electrons and radiant energy to take place in amounts $h\nu$, where h is Planck's constant and ν is the frequency of the radiation. The object of the present note is to direct the attention of physicists to this communication, and to point out that the same mechanism may be employed in forming a model of static atom, in which electrons, instead of revolving in orbits of a more or less complicated description, may be regarded as occupying, or oscillating about, positions of equilibrium.

§2. Prof. Whittaker infers that when an atom is caused to emit radiation by collision with an electron, the mechanism within the atom must be such that the approaching electron induces in it what he terms a "magnetic current"—*i.e.*, the magnetic analogue of an electric current: or at any rate something which behaves like a magnetic current. To illustrate this a model is described which is essentially similar to one of those which have been proposed by Sir Alfred Ewing* for the purpose of explaining induced magnetisation. The magnetic structure consists of a number of magnetic poles revolving in a circle of radius a, their corresponding poles of contrary sign being at rest at the centre of the circle. When this magnetic wheel is rotating about its axis with angular velocity $\dot{\psi}$, it sets up an electric field such that an electron (charge e, mass m) situated at a point on the axis at a distance x from the centre is acted on by a force $Mea^2\dot{\psi}/(a^2+x^2)^{3/2}$ along the axis. Here M denotes the sum of the magnetic poles (of one sign) in the magnetic wheel. When the electron is moving along the axis, it creates a magnetic field which tends to set the wheel in rotation. The equations of motion of the electron and of the magnetic wheel having been written in the form

$$m\ddot{x}+\frac{Mea^2\dot{\psi}}{(a^2+x^2)^{3/2}}=0. \quad \ldots\ldots\ldots\ldots \quad (1)$$

and

$$A\ddot{\psi}-\frac{Mea^2\dot{x}}{(a^2+x^2)^{3/2}}=0. \quad \ldots\ldots\ldots\ldots \quad (2)$$

where A denotes the moment of inertia of the wheel, two first integrals are obtained

* Ewing, Proc. Roy. Soc., Vol. C., p. 449 (1922); Phil. Mag., Vol. XLIII., p. 493 (1922); Proc. Roy. Soc. Edin., Vol. XLII., p. 97 (1922).

without difficulty. One of these is the equation of conservation of energy of the system, and may be written

$$\tfrac{1}{2}A\dot{\psi}^2+\tfrac{1}{2}m\dot{x}^2=\tfrac{1}{2}mu^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

assuming that initially the wheel is at rest, and the electron is projected from $x=-\infty$ with velocity u. The second integral of the equations of motion is written by Prof. Whittaker in the form

$$A\dot{\psi}-\frac{Mex}{(a^2+x^2)^{1/2}}=Me \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

It is worthy of notice that this equation may be interpreted as representing conservation of angular momentum, provided we take into consideration angular momentum in the electromagnetic field. Adding Me to each side, the equation may be written

$$A\dot{\psi}+Me\left\{1-\frac{x}{(a^2+x^2)^{1/2}}\right\}=2Me \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

or

$$A\dot{\psi}+\frac{Me\Omega}{2\pi}=2Me \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where Ω denotes the solid angle subtended by the magnetic wheel at the electron. In this equation the first term represents the angular momentum of the magnetic wheel, and it may be observed in passing that this also (or rather the corresponding energy) is regarded later in Prof. Whittaker's Paper as located in the electromagnetic field. The second term may be taken to correspond to the angular momentum in the field arising from the presence of the electron and what is, essentially, a magneton. The result can be obtained from an extension of McLaren's theorem with regard to the angular momentum of a magneton.*

It follows from these equations that when the initial volocity u is small, the electron travels to a definite point on the axis where it comes to rest and the motion is reversed. When u has the value $eM/\sqrt{(Am)}$, the electron is able to get just as far as the magnetic structure, but not beyond it ; when u is greater than this value, the reversal point is on the further side of the magnetic structure, and when u has the value $2eM/\sqrt{(Am)}$, or any greater value, the electron is able to pass completely through and out of the magnetic system, so as to be free from its influence.

In this latter case ω, the final value of $\dot{\psi}$ (namely, when $x=\infty$) is given by

$$A\omega=2eM \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

and an amount of energy $U=\frac{1}{2}A\omega^2=\dfrac{2e^2M^2}{A}$ is lost by the electron and gained by the magnetic structure. *Unless the initial energy of the electron is as great as U, the electron gives up no energy to the magnetic structure, but experiences an " elastic impact " ; if, however, the initial energy of the electron is greater than U, it gives up exactly the amount U of energy, and retains the rest.*

§ 3. The energy absorbed by the atom from the moving electron becomes

* S. B. McLaren, Phil. Mag., Vol. XXVI., p. 800 (1913) ; H. S. Allen, Phil. Mag., Vol. XLI., p. 119 (1921).

resident in the atom as the energy of a " magnetic current." Prof. Whittaker then considers the transformation of this energy into the radiant form by the mechanism within the atom. Just as a closed electric current is equivalent to a magnetic shell, so a magnetic current is equivalent to an electric shell—an electric shell being to all intents and purposes what is called a charged condenser in electrostatics. It is found that the charge on either plate of the condenser which is equivalent to the magnetic current is numerically equal to the charge on the bombarding electron. Now a Hertzian oscillator is essentially a condenser in the act of discharging, the frequency ν being given by

$$V=\frac{1}{2\pi\sqrt{LC}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

It is assumed that there are two factors associated with the vibrator in any particular atom which play the same part as the capacity C and the inductance L in the differential equation for the oscillatory discharge of a condenser.

Now the quantity $e^2\sqrt{(L/C)}$ has the same dimensions in every possible system of units, namely—the dimensions of action. This quantity, which may be regarded as a natural constant of Action, is accordingly represented by h/π, so that

$$\sqrt{\frac{L}{C}}=\frac{h}{\pi e^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

This may be taken to indicate that the Hertzian oscillators in the atoms are similar to each other in structure and differ only in scale.

From (8) and (9) we have

$$h\nu=\frac{e^2}{2C} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

The right hand side of this equation represents the energy of the charged condenser which, in turn, is equal to U, the energy of the " magnetic current." So we find

$$h\nu=U \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

which is precisely Planck's equation connecting the frequency of the emitted radiation with the amount of kinetic energy absorbed from the bombarding electron.

The original Paper, together with other Papers which formed contributions to the ensuing discussion on Quantum Theory and Atomic Structure, should be consulted for further particulars, modifications and developments of the suggested mechanism.*

§ 4. In the discussion on Prof. Whittaker's Paper I suggested that the magnetic wheel in his model might be replaced by two thin anchor rings, representing the magnetons either of McLaren or of Parson, placed near together with their planes parallel and having a common axis. To obtain the required distribution of the lines of magnetic force the rings must be placed so that the magnetic force between them is one of repulsion. Such an arrangement is equivalent to a magnetic shell forming the curved surface of a cylinder having its edges coincident with the two rings. It is of interest to consider what modifications are required in Prof. Whittaker's equa-

* Proc. Roy. Soc. Edin., Vol. XLII. (1922).

tions if we substitute such a magnetic shell for his magnetic wheel. If φ denote the strength of the shell and d the distance between the two rings, I find that in equations (1) to (7) above the quantity M must be replaced by $2\pi\varphi d$. If we prefer to think of two ring electrons with currents circulating round them in opposite directions, φ is proportional to the strength of the current in each ring.

§ 5. We pass on to consider how Whittaker's mechanism may be employed in constructing a model of a static atom with electrons occupying fixed positions, or oscillating about positions of equilibrium. Dr. Irving Langmuir, in a Paper read before the American Physical Society,* and in a Discussion on the Quantum Theory at the Edinburgh meeting of the British Association, has discussed the forces within a static atom. "If in addition to the Coulomb forces between charged particles we assume the existence of another force (quantum force) equal to $Fq=1/mr^3 . (nh/2\pi)^2$ acting between an electron and a nucleus, we find that a stationary electron is in stable equilibrium when its distance r from a nucleus is the same as the radius of a circular orbit corresponding to a stationary state in Bohr's theory. The total energy of the electron is also the same as that given by Bohr's theory. The frequency of oscillation about the position of equilibrium is identical with the frequency of revolution of the electron in the Bohr atom. Thus the Rydberg constant and the Balmer series can be deduced from this law of force without assuming moving electrons." Now it appears that Whittaker's mechanism provides a force of exactly the type required in Langmuir's theory.

We assume that the angular momentum of the magnetic wheel in its steady state is determined by Nicholson's quantum relation, so that, from (7)—

$$A\omega=2eM=nh/2\pi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where n is an integer.

As we have seen in § 2, the force on an electron at a point on the axis of the wheel is $Mea^2\dot{\psi}/(a^2+x^2)^{3/2}$. When $\dot{\psi}=\omega$ and x is large in comparison with a this becomes $Mea^2\omega/r^3$, or, substituting the values of Me and ω given by (12)—

$$\frac{a^2}{2Ar^3}\left(\frac{nh}{2\pi}\right)^2$$

This agrees precisely with Langmuir's "quantum force," provided $A=\frac{1}{2}ma^2$. This might be taken to indicate that the moment of inertia of the magnetic wheel is the same as would be obtained by imagining a mass equal to that of an electron distributed uniformly over a circular disc of radius a. It must, however, be remembered that we are to regard the inertia of the magnetic structure as located in the electromagnetic field.

§ 6. Taking the electrostatic attraction between electron and nucleus as e^2/r^2, and assuming the quantum force to be a repulsion of amount $1/mr^3 . (nh/2\pi)^2$, the distance between electron and nucleus in the equilibrium position is—

$$r_0=\frac{n^2h^2}{4\pi^2me^2}$$

which is the radius of a circular orbit in Bohr's theory. Hence the force of repulsion may be written as r_0e^2/r^3. Assuming the massive nucleus to remain fixed and the

* Langmuir, Phys. Rev., Vol. XVIII., p. 104 (1921).

electron to be displaced from its equilibrium position by a small distance, dr, we easily find for the value of the restoring force $\frac{e^2}{r_0^3}dr$. The frequency of the resulting oscillation is $\frac{1}{2\pi}\sqrt{\frac{e^2}{r_0^3 m}}$, which reduces to $\frac{4\pi^2 me^4}{n^3h^3}$, the value for the frequency of revolution of the electron in the Bohr atom. These results are included amongst those stated by Langmuir, but it may be pointed out that Langmuir's theory may be applied to a nucleus of finite mass M, leading to the same correction for the mass of the nucleus as is given by Bohr's theory. Thus, in the value of the Rydberg constant we must substitute for m the quantity $\frac{Mm}{M+m}$, as in Bohr's theory. It appears, therefore, that the quantum mechanism leads to results which are identical with those of Bohr's theory, so long as we consider circular orbits, and it is not impossible that a more accurate investigation, taking into account terms of higher order in the displacement of the electron, would lead to results comparable with those obtained in Sommerfeld's theory from a consideration of elliptic orbits.

DEMONSTRATION of a New Method of Producing Visual Effects by Means of Sound. *By* Dr. E. E. Fournier d'Albe.

A membrane of thin rubber is stretched horizontally across the end of a tube about 2 in. in diameter, and a drop of mercury, about 1 in. in diameter, is placed upon the membrane. Sound waves entering the tube produce oscillations in the membrane, and these are communicated to the edges of the mercury drop, when they travel to the centre and out again. The incoming and outgoing waves produce stationary ripples in the mercury surface, which remain in position so long as the note is held, and change with every variation in the pitch of the note, the change taking place in about 1/20th of a second, so that a piece of music can be made practically " visible " by means of the pattern of ripples. The wave-length varies inversely as the pitch of the note.

The patterns were thrown on a screen, so that the audience could follow a piece of music played on a gramophone.

XXIX. *The Neon Tube as a Means of Producing Intermittent Currents.* By S. O. Pearson, *B.Sc., and* H. St. G. Anson.

Received June 7, 1922.

(Communicated by A. Russell, M.A., D.Sc.)

ABSTRACT.

The Paper relates to an experiment in which a neon tube and a condenser in parallel are connected in series with a high resistance and source of current.

In these circumstances intermittent current is found to pass through the lamp, and the Paper discusses the conditions governing the frequency and duration of the resulting flashes.

In order to explain clearly the phenomenon to be described here it will be necessary first to consider briefly some of the chief characteristics of a neon tube. The tube consists essentially of a glass blub enclosing two metal electrodes and filled with neon gas at a low pressure. Experiments were carried out with a number of neon lamps as supplied by the General Electric Co. under the trade name of "Osglim."

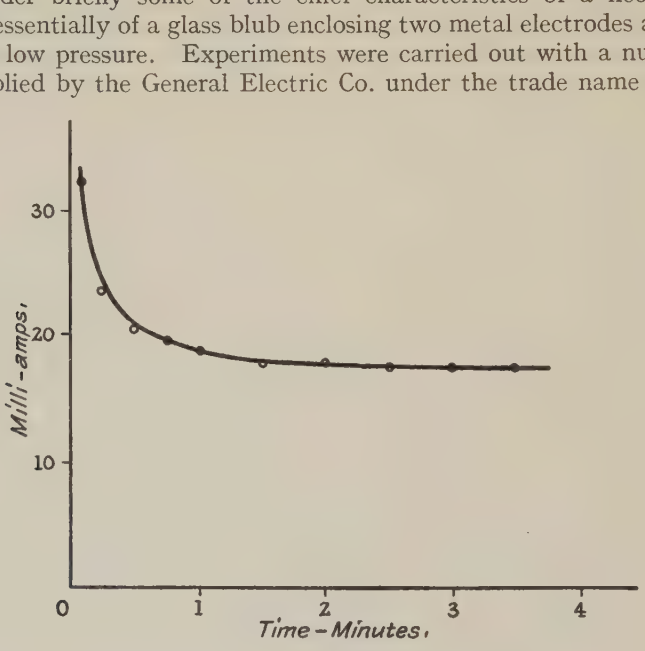

Fig. 1.—Variation of Current with Time.

In these lamps the electrodes have various shapes according to the purpose for which they are intended, *e.g.*, letters of the alphabet, &c.

When a suitable difference of potential is applied to the electrodes a discharge takes place through the gas and an orange-coloured glow is formed over the entire surface of the negative electrode or cathode. Under normal conditions the anode does not glow at all. It will be seen later that the effective resistance between the electrodes, when the lamp is glowing, decreases with increase of current; hence a steadying or ballasting resistance is connected in series and mounted inside the cap of the commercial type of lamp. In order to carry out the experiments described the resistances were removed from the caps and connected externally,

thus enabling the actual difference of potential between the electrodes themselves to be measured.

When the lamp is first switched on the temperature of the gas in the bulb begins to rise, and hence its pressure increases. This may account for the fact that the current does not reach a steady value until several minutes have elapsed after first switching on. The initial value may be more than double the final steady value of the current for a given applied voltage. The curve of Fig. 1 shows how the current varied with time after first switching on with the lamp cold; the pressure across the electrodes was kept constant at 175 volts. The curve appears to be very similar in shape to an ordinary curve of cooling or "die-away" curve. It is evidently necessary to allow an interval of at least three or four minutes to elapse before measuring the current for any given voltage.

D.C. Characteristic.

The steady current flowing through the lamp was measured for various values of the potential difference applied to the electrodes. It was found that as the voltage was gradually increased from zero, no current flowed and the lamp did not

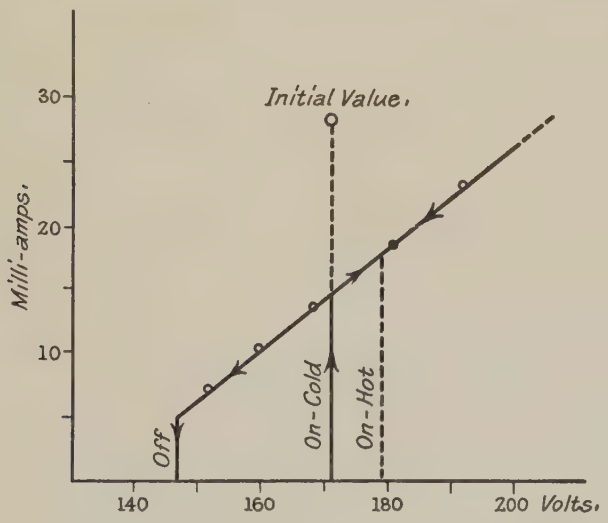

Fig. 2.—Characteristic Curve of Neon Tube.

commence to glow until a value of 171 volts was reached. At this point the current suddenly increased from zero to 28·4 milliamps, and the glow was established. This critical voltage seems to be quite definite for a given temperature, but it was found that with the lamp hot after running for 15 minutes the critical voltage had risen to 179 volts. The initial value of the current at 171 volts was over 28 milliamps, but it reached a steady value of 14·7 ma. after about five minutes. The steady values of the current were obtained for increasing values of the voltage, and from the curve of Fig. 2 it will be observed that the current follows very approximately a straight line law. On reducing the voltage in stages it was found that the current did not cease to flow until the potential difference had fallen to

147 volts—a figure well below the critical starting voltage. Mr. J. H. Ryde has shown that the steady current taken by the lamp is given by :—

$$I=(V-e)/\{(MA)^{-1}+R\}$$

where

V=voltage across lamp and series resistance,
e=constant (viz., the extrapolated intercept on the V-axis of the straight part of the V, I curve),
M=a constant of the order of 10^{-4}, dependent on the area and material of the electrodes and the pressure and purity of the gas,
A=area of cathode,
R=resistance fitted in series with lamp.

In order to determine the effects of temperature on the steady values of the current and on the critical values of the voltage, a lamp was immersed in water

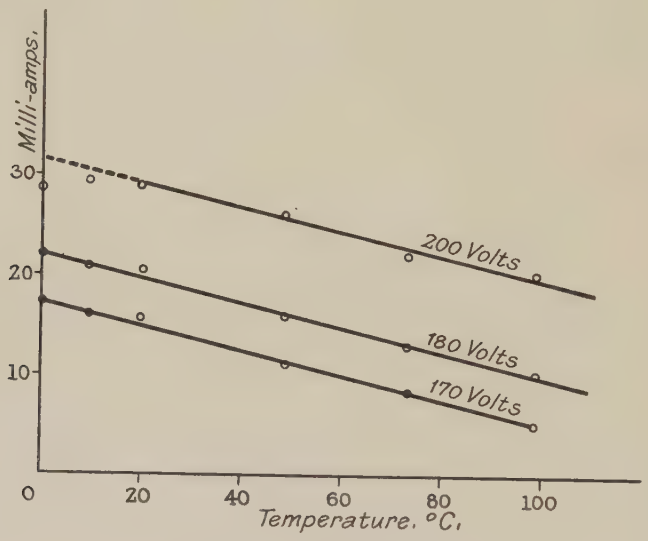

Fig. 3.—Effect of Temperature on Current.

and tests made with the water at various temperatures between zero and 100°C. The curves of Fig. 3 show how the steady values of the current are dependent on the temperature—the higher the temperature the lower the current for any given voltage. Three curves are given, namely, at 200, 180 and 170 volts respectively. This seems to show that the change of current with time after first switching on is, to some considerable degree, accounted for by the rising temperature. It has been stated by some observers that this change in current with time is due to occluded impurities which are admitted in order to reduce the critical voltages and to prevent spluttering and consequent blackening of the glass ; and that if the gas be pure there is no change of current with time. This implies that temperature plays no part—a conclusion which does not seem to tally with the experimental results given.

Fig. 4 shows the effect of the temperature of the surrounding medium on the upper and lower critical voltages.

Flashing of the Lamp.

We have seen that no current flows until the voltage across the electrodes reaches a certain definite value ; that is, the resistance is to all intents and purposes infinitely great for all values of voltage up to the value at which the discharge through the gas commences. When a condenser of capacity K farads is connected

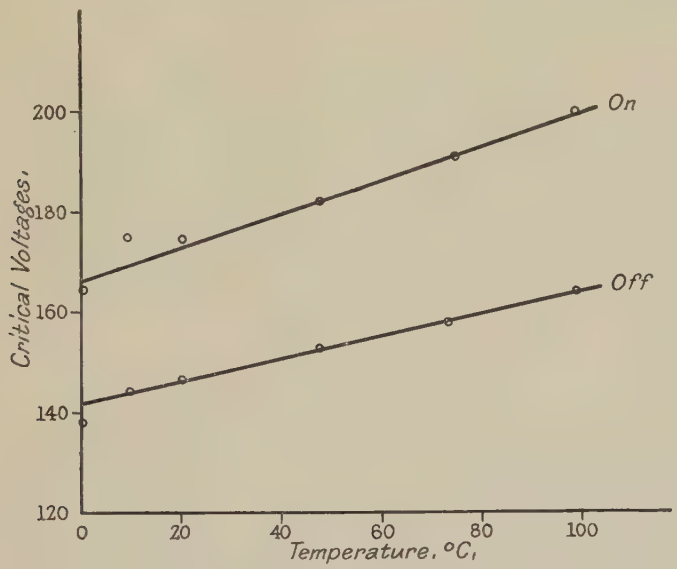

Fig. 4.—Effect of Temperature on Critical Voltages.

in series with a high resistance R and a constant voltage V is suddenly applied to the ends of the circuit, the condenser will begin to acquire a charge and the voltage v across its terminals will rise according to the law $v=V\left(1-\varepsilon^{-\frac{t}{KR}}\right)$, where t is time in seconds after switching on. If the lamp is connected in parallel with the condenser as in Fig. 5, it will obviously flash on as soon as the voltage across the

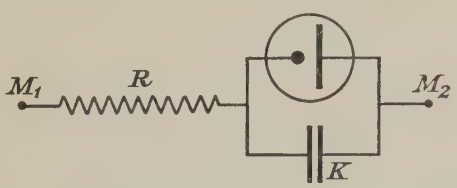

Diagram of Connections.

Fig. 5.

condenser reaches the critical value at which the discharge through the gas commences. When this occurs the condenser becomes shunted by a fairly low resistance—that of the lamp—and begins to lose its charge in consequence. The lamp will continue to glow until the pressure across it and the condenser falls to the lower critical voltage at which the current through the lamp ceases. If a and b represent the upper and lower critical values respectively of the voltage, the glow

will last while the voltage falls from a to b. As soon as the glow ceases, the condenser charges up again from b to a, and so the process is repeated indefinitely.

By adjusting the values of R and K the frequency of flashing can be varied over a very wide range. The authors have obtained frequencies as low as one flash in several minutes and so high as to be above the range of audibility. The audible frequencies of flashing are best detected by means of a telephone connected in the condenser branch circuit.

Calculation of Periodic Time.

The dark period lasts whilst the condenser is charging up from the voltage b to the voltage a. This is quite easily calculated if we know definitely the values of a and b. There is no difficulty in measuring a experimentally, since the gas is quite cool when the glow commences; but in the case of the lower critical voltage b, a difficulty arises—the duration of the light period is a very small fraction of a second; in fact, in some cases it may only last for one-millionth of a second. We shall see later that the light period is very short compared to the dark period

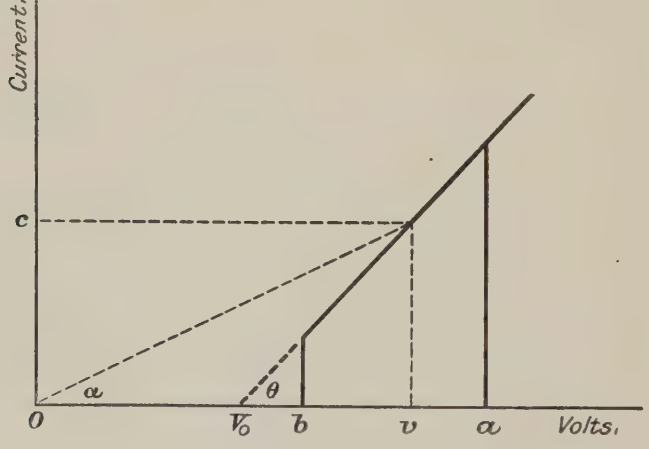

Fig. 6.—Typical Characteristic Curve.

and hence there is very little heating effect on the gas when the lamp is flashing, which means that the gas is still cool when the light period comes to an end. To measure the lower critical voltage experimentally it is necessary to reduce the applied voltage gradually with the lamp glowing, which allows the gas to heat up; and so the true value with the gas cool cannot be obtained.

The time of one dark period differs from the time of one complete cycle by much less than 1 per cent. Hence, if the time of one complete cycle is measured it is possible to calculate the lower critical voltage very approximately.

Let T_1=duration of one dark period

=time for condenser to charge from b to a,

then

$$T_1 = KR \log (V-b)/(V-a) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In a particular case the values were as follows :—

T_1=0·83 sec.
K =1·0 microfarad
R =10^6 ohms
V =200 volts
a =171 volts

from which we get :—

Lower critical voltage, b=139·6 volts.

In order to calculate the duration of one light period it is necessary to know how the resistance of the glowing lamp varies with the voltage across the electrodes. Fig. 6 shows a typical characteristic curve, and from it we can deduce an expression for the resistance in terms of voltage across the electrodes. Put

$$\cot\theta = r' = (v-v_0)/c$$

Now $c=v/r$, where r= effective resistance of lamp.

Therefore $r' = r(v-v_0)/v$

and $r = v \cdot r'/(v-v_0)$ ohms.

We are now in a position to find the duration of one light period.

Let v=voltage across the condenser at any time t seconds after commencement of flash. When $t=0$, $v=a$.

Charging current from supply and flowing through R

$i_1=(V-v)/R$, where V= constant applied voltage.

Current flowing through lamp

$$i_2 = v/r = (v-v_0)/r'$$

Resultant current flowing from condenser, or rate of discharge

$$i = i_2 - i_1$$
$$= (v-v_0)/r' - (V-v)/R$$
$$= v(1/R+1/r') - (V/R+v_0/r')$$

Also rate of discharge

$$i = -\frac{dq}{dt} = -K\frac{dv}{dt}$$

Hence $$\frac{dv}{dt} + \frac{1}{K}(1/R+1/r')v - \frac{1}{K}(V/R+v_0/r') = 0,$$

the solution of which is

$$v = \frac{Vr'+v_0R}{R+r} + A\varepsilon^{-\frac{R+r'}{KRr'}t},$$

where A is a constant which can be determined from the initial conditions, viz., when $t=0$, $v=a$.

Hence $$A=-\frac{Vr'+v_0R}{R+r'}$$

Therefore voltage across lamp at any time t after commencement of flash is

$$v=\frac{Vr'+v_0R}{R+r'}\left(1-\varepsilon^{-\frac{R+r'}{KRr'}t}\right)+a\varepsilon^{-\frac{R+r'}{KRr'}t}$$

Let $$\frac{Vr'+v_0R}{R+r'}=Q$$

Then $$v=Q+(a-Q)\varepsilon^{-\frac{R+r'}{KRr'}t}$$

When v falls to b,

$t=T_2$=duration of light period.

Therefore $$b=Q+(a-Q)\varepsilon^{-\frac{R+r'}{KRr'}T_2}$$

or $$T_2=\frac{KRr'}{R+r'}\log\frac{a-Q}{b-Q} \quad \ldots\ldots\ldots\ldots \quad (2)$$

where $$Q=\frac{Vr'+v_0R}{R+r'}$$

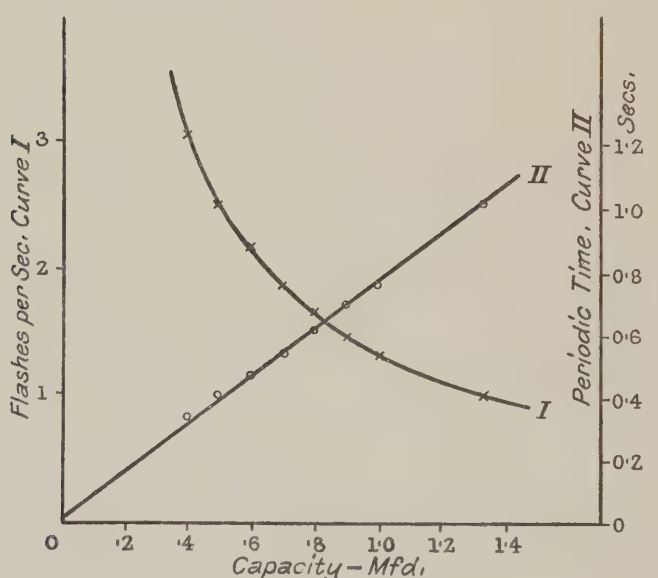

FIG. 7.—VARIATION OF FREQUENCY WITH CAPACITY.

In the case considered above the duration of the light period worked out at about 0·002 second.

The total time of one complete period is equal to the sum of the times of the dark and light periods respectively.

That is, $$T=T_1+T_2$$

$$=KR\left\{\log\frac{V-b}{V-a}+\frac{r'}{Rr'}\log\frac{a-Q}{b-Q}\right\}$$

We see from the above that the time of one complete cycle is directly proportional to the capacity in parallel and the resistance in series with the lamp. This was proved experimentally, and in Fig. 7 curves are given showing how the periodic time and its reciprocal, the number of flashes per second, vary with change of capacity. Change of applied E.M.F. also affects the periodic time, and two curves

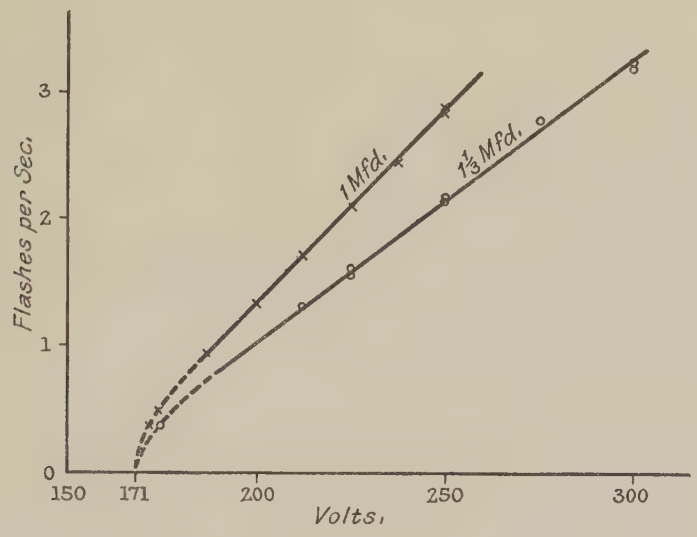

FIG. 8.—VARIATION OF FREQUENCY WITH APPLIED VOLTAGE.

are shown in Fig. 8. In both cases the series resistance was 1 megohm, but two different capacities, namely, 1 microfarad and 1·333 microfarads, were used. It will be noticed that the lower part of each curve is drawn dotted and made to meet

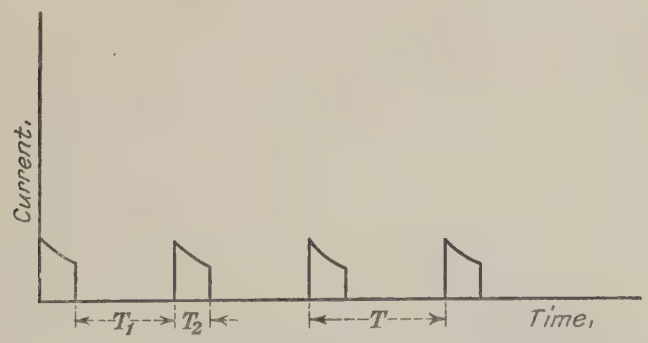

FIG. 9.—WAVE SHAPE OF INTERMITTENT CURRENT.

the V-axis at 171 volts. This is obviously the case, for when the voltage is below 171, *i.e.*, below the critical starting voltage, no flashing can possibly occur.

From a consideration of the laws of charge and discharge of a condenser, in conjunction with the characteristic curve of a neon tube, it follows that the wave-shape of the intermittent current obtained from such an arrangement will be

somewhat as shown in Fig. 9. This may possibly be modified by insertion of inductance or by including a tuned or resonant circuit for any particular frequency.

The device which has been described here provides a very simple means of producing intermittent currents without the use of any moving mechanism or contacts, and should prove particularly useful over the audible range of frequencies.

There is no doubt that the three-electrode thermionic valve provides the most satisfactory means of generating very high or radio frequencies, but in order to get an audio frequency current from a thermionic valve, very costly apparatus is necessary, whereas, with the flashing neon lamp the apparatus is extremely simple and inexpensive.

Among the suggested possible uses of the arrangement are :—

(1) Audio frequency—Telephonic measurements.
Stroboscopic measurements.

(2) High frequency—Radio communication and measurements.

DEMONSTRATION of (a) A Magnetic Pivot, and (b) A Self-charging Electroscope. *By Major* C. E. S. Phillips, *O.B.E.*

A Magnetic Pivot.

This device may take various forms, and is intended to provide a means of rapidly setting up a delicate pivot in the laboratory. In the first of two examples exhibited a steel knitting needle stood vertically with its lower end resting upon a plate of glass, while the upper end was supported (without touching) by a permanent magnet held in a clamp immediately above.

The magnet could be lowered till the needle was nearly lifted from the glass plate, and, since the upper end was free and the lower end only pressing upon its bearing point with an extremely small force, the friction of the system was reduced to a minimum. It was then shown that the needle was very free to rotate about its axis, and that when a short arm was attached radially to the centre of it, and the needle itself slightly inclined, a control was afforded by the fact of the arm always moving so as to place its mass centre as low as possible. Under these conditions, but with the needle held nearly vertically, a slight lateral movement of the base-plate gave rise to a large deflection of the radial arm—possibly a useful application as an optical lever.

The other exhibit was a small sewing needle standing vertically with its point resting lightly upon the surface of mercury, while its upper end was supported by a magnet as before. It was explained that a convenient form of the pivot is also obtained by placing the magnet above the concave surface of a watch glass and a needle below with its point held against the convex surface of the glass. In this way large masses of magnetic material can be supported for rotational experiments in which it is required to eliminate friction as far as possible. Many other forms of the device will suggest themselves.

A Self-charging Electroscope.

This electroscope was originally designed and used in 1910-11 for radioactive measurements, but was then found to have a serious defect. In 1911 Prof. Zeleny described an instrument working upon something the same plan, but both this and an improved form suggested in 1915 by Prof. Horton are not free from this same defect—viz., the occasional adhesion of the gold leaf to the charged surface with which it periodically comes into contact. In the original form of this electroscope the leaf moved intermittently against a carbon point, which was kept charged to a constant potential of −200 volts, while the leaf stem was connected to an earthed ionisation-chamber, so that with, say, radium present the leaf was continually charging up, and then periodically discharging by touching the carbon point. The number of kicks of the leaf per minute was, of course, dependent upon the extent of the ionisation in the chamber. In the electroscope exhibited the occasional "adhesion" of the leaf is prevented by coating the object touched by the leaf with a layer of fine carbon (arc lamp) powder. The powdered electrode may in fact be approached so closely to the leaf (or fine carbon filament suspended from a gold leaf hinge) that an almost imperceptible movement results which continues regularly and without appreciable adhesion. It was also explained that the arrangement has been made to give a sharp sound audible in a telephone at the instant the leaf or fibre strikes against the powdered electrode, and that this result is being utilised in the design of a recording electroscope. It is expected that the device will prove useful for the measurement of X-ray intensity, &c., and enable electroscopic observations to be made at a safe distance from the source of radiation.

INDEX.

A

B

C

D

E

F

G

H

I

J

L

M

N

O

Q

R

S

T

V

W

PUBLICATIONS OF THE PHYSICAL SOCIETY.

THE SCIENTIFIC PAPERS
OF THE LATE
SIR CHARLES WHEATSTONE, F.R.S.
Demy 8vo, cloth. Price 12s.; to Fellows, 6s.

Uniform with the above.

THE SCIENTIFIC PAPERS OF
JAMES PRESCOTT JOULE, D.C.L., F.R.S.
Vol. I. 4 Plates and Portrait, price 18s.; to Fellows, 9s.
Vol. II. 3 Plates, price 12s.; to Fellows, 6s.

PHYSICAL MEMOIRS.

PART I.—VON HELMHOLTZ, On the Chemical Relations of Electrical Currents. Pp. 110. *Price 6s.; to Fellows, 3s.*

PART II.—HITTORF, On the Conduction of Electricity in Gases; PULUJ, Radiant Electrode Matter. Pp. 222. *Price 12s.; Fellows, 6s.*

PART III.—VAN DER WAALS, On the Continuity of the Liquid and Gaseous States of Matter. Pp. 164. *Price 12s.; to Fellows, 6s.*

REPORT ON RADIATION AND THE QUANTUM THEORY.
By J. H. JEANS, M.A., F.R.S.
New Edition in Preparation.

REPORT ON THE RELATIVITY THEORY OF GRAVITATION
By A. S. EDDINGTON, M.A., M.Sc., F.R.S.
Plumian Professor of Astronomy and Experimental Philosophy, Cambridge.
Third Edition.—*Price 6s.; to Fellows, 3s. Bound in cloth, 8s. 6d.; to Fellows, 6s.*

REPORT ON SERIES IN LINE SPECTRA.
By A. FOWLER, F.R.S.,
Professor of Astrophysics, Imperial College of Science, South Kensington, London.
Price to Non-Fellows, 12s. 6d.; to Fellows, 6s. 3d. Bound in Cloth, 15s., to Fellows, 9s.

THE TEACHING OF PHYSICS IN SCHOOLS.
Price to Non-Fellows, 1s. 6d. net, post free 1s. 8d.

METROLOGY IN THE INDUSTRIES.
Price to Non-Fellows, 1s. 6d. net, post free 1s. 8d.

DISCUSSION ON LUBRICATION.
Price to Non-Fellows, 1s. 6d. net, post free 1s. 8d.

DISCUSSION ON ELECTRIC RESISTANCE. *Price 2s. 6d. net.*

DISCUSSION ON HYGROMETRY. *Price 5s. net.*

PROCEEDINGS.

The "Proceedings" of the Physical Society can be obtained at the following prices:—

Vol. I. (3 parts) bound cloth, 22s. 6d.
Vols. II., IV., V., XXIII., XXV., XXVI., XXVII., XXVIII., XXIX., XXX. & XXXI. (5 parts each), cloth, 34s. 6d.
Vols. III., VI. to XII. & XXII. (4 parts each), bound cloth, 28s. 6d.
Vol. XIII. (13 parts, each containing Abstracts), bound cloth (without Abstracts), 70s. 6d.
Vols. XIV. & XV. (12 parts, each containing Abstracts), bound cloth (without abstracts). 34s. 6d.
Vols. XVI. & XIX. (8 parts each), bound cloth, 52s. 6d.
Vols. XVII., XVIII. & XXI. (7 parts each), bound cloth, 46s. 6d.
Vols. XX. & XXIV. (6 parts), bound cloth, 40s. 6d.
Most of the parts can be purchased separately, price 6s., by post 6s. 3d. Fellows can obtain the *Proceedings* (in parts) for their personal use at half the above prices.

ABSTRACTS OF PHYSICAL PAPERS FROM FOREIGN SOURCES.
VOLS. I. (1895), II. (1896), III. (1897), 22s. 6d. each; Fellows, 11s. 3d.

Strong cloth cases for binding the "Proceedings," price 3s. 6d. each, post free.

BLAKESLEY, T. H. A Table of Hyperbolic Sines and Cosines. *Price 2s. 3d.; to Fellows, 1s. 2d.*

LEHFELDT, R. A. A List of Chief Memoirs on the Physics of Matter. *Price 3s.; to Fellows, 1s. 6d.*

Applications for the above Publications should be sent direct to
FLEETWAY PRESS, LTD.,
3-9, DANE STREET, HIGH HOLBORN, LONDON W.C.1.

CONTENTS.